MINNESOTA WHEAT
RESEARCH & PROMOTION COUNCIL

MINNESOTA WHEAT RESEARCH REVIEW

ON-FARM CROPPING TRIALS
NORTHWEST & WEST CENTRAL

2022

2022 On-Farm Trials | UMN Extension On-Farm Cropping Trials

The mission of University of Minnesota Extension and NWROC is to contribute within the framework of the Minnesota Agricultural Experiment Station (MAES) and the College of Food, Agricultural, and Natural Resource Sciences to the acquisition, interpretation and dissemination of research results to the people of Minnesota. Additionally, its intent is to add to the knowledge base of the United States and globally. Within this framework, major emphasis is placed on research and education that is relevant to the needs of northwest Minnesota, and includes projects initiated by Center scientists, other MAES scientists and state or federal agencies.

Contributors to the On-Farm Trials include: Dr. Angie Peltier, Extension Regional Office, Crookston; Dr. Jared Goplen, Extension Regional Office, Morris; Dr. Daniel Kaiser, Soil, Water, and Climate, University of Minnesota; Arthur Vieira Ribeiro, Robert Koch and Bruce Potter, Extension Integrated Pest Management, University of Minnesota, SWROC; Andrew Lueck, Owner/Research Lead, Next Gen Ag, Renville; Maykon Jr. da Silva and Seth Naeve, Dept. of Agronomy and Plant Genetics, University of Minnesota; Dr. Dean Malvick, Dept. of Plant Pathology, University of Minnesota; . Megan McCaghey, Ph.D., Assistant Professor University of Minnesota Department of Plant Pathology.

These projects were made possible thanks to the hard work of many people. This includes farmers, County and Regional Extension Educators, and specialists who participated in these trials.

Previous On-Farm Cropping Trials booklets can be found at: http://mnwheat.org/council/wheat-research-reports/.

2022 Wheat Research Review

Last year, the Minnesota Wheat Research & Promotion Council allocated approximately $867,000 of the total $1.8 million in check-off income to wheat research, including the On-Farm Research Network, spring wheat breeding programs in Minnesota and South Dakota, and university production research. This review summarizes funded university research from the 2022 cropping season.

Wheat Research Project Funding Process:
Each year in September, the Minnesota Wheat Research & Promotion Council requests wheat research pre- proposals from researchers in Minnesota, North Dakota and South Dakota. Researchers are given an opportunity to meet with a small group of wheat growers to get feedback on project ideas. Pre-proposals are reviewed by the Research Committee of the Minnesota Wheat Council. This Committee listens to presentations from each researcher and then the Committee determines which ones should be asked to submit full proposals.

The proposals are evaluated on the following criteria: 1) Is it a priority for growers? 2) Impact on Profitability?3) Probability of Success? 4) Cost vs. Benefit?

At the end of January, the committee meets once again to review the full proposals and make funding recommendations to the Minnesota Wheat Research & Promotion Council.

In addition to the project reports printed and distributed through this booklet, some of the project researchers deliver oral presentations at the Prairie Grains Conference, Best of the Best Workshops and Small Grains Updates - Wheat, Soybean and Corn. Also, some of the projects are reported in Prairie Grains Magazine. The Minnesota Wheat Research Committee comprises wheat growers, agronomists, unbiased researchers and industry representatives.

Information about the committee and previously funded research can be found online at www. mnwheat.org/council. Click on the Research Committee tab.

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On-Farm Cropping Trials for Northwest & West Central Minnesota

Wheat Research Reports - Funded in part by the Minnesota Wheat check-off

European corn borer survey – 2017-2022: Northwest Minnesota

Cooperators: Cooperating producers and crop advisors in Becker, Beltrami, Clay, Kittson, Mahnomen, Marshall, Norman, Pennington, Polk, Red Lake and Roseau Counties.

Purpose of Study:
European corn borer (ECB) larvae tunnel into stalks and ear shanks (**Figure 1**). Feeding affects the transfer of water and nutrients within the plant and can directly affect yield by reducing kernel weight and number. ECB feeding can indirectly affect yield when tunnels cause stalk breakage, ear drop, or allow the entry of stalk rot and ear mold fungi.

Figure 1. European corn borer (*Ostrinia nubilalis*). Photo: Clemson University, USDA Cooperative Extension Slide Series, Bugwood.org.

<u>ECB and Bt corn.</u> More than 25 years ago scientists found a way to transfer a gene from a soil-borne bacterium called *Bacillus thuringiensis* (Bt) into the corn genome. Bt corn was approved for commercial use in 1996. Within the corn plant tissues, this gene produces a protein that when ingested by larvae breaks down to a toxin which kills larvae by allowing mid-gut contents to leak into the rest of the body cavity. Additional Bt traits that target different above- and below-ground insect pests have since been incorporated into some hybrids.

The only way to manage ECB before Bt corn was developed, was to closely monitor ECB moth flights and scout for larvae and egg laying. If ECB populations warrant, foliar insecticide applications can provide control if they are carefully timed as the larvae are only susceptible to insecticides for 10 to 14 days. After that time, 3rd instar larvae begin to tunnel into the stalk, ear or ear shank where they are protected from insecticide applications. This timing can be difficult particularly in areas of the state where both a single generation and multiple generation biotypes of ECB exist. Historically, the single generation (univoltine strain) has predominated in NW Minnesota.

Even the best-timed insecticide application is less effective than growing a hybrid with the Bt trait. Depending on the hybrid and trait package Bt corn can cost up to $20/acre more than conventional seed. In the current economic environment, $20/acre is a big deal and is a major driver of non-Bt corn hybrid seed purchases. During the past 4 years in MN, Bt corn use for above-ground traits for stalk and ear pests has ranged from 85-88% (USDA average).

High adoption of Bt corn has also occurred in NW MN. This has resulted in area-wide suppression of ECB populations, protecting even the non-Bt acres.

<u>Study Objectives</u>. Some objectives of the MN Corn Research & Promotion Council-sponsored 2017-2022 fall ECB survey in NW MN are to answer the following questions:

1) Are there changes in ECB population densities over time?
2) To what extent does the areawide suppression effect occur in the NW?
3) Have any population shifts taken place? ie. is the Bt trait still effective (Bt-resistant corn borer have been found in eastern Canada but fortunately they are a different strain than occurs in MN).

Results:
During 2017, 2018, 2019, 2020, 2021 and 2022 a total of 13, 30, 55, 28, 43 and 38 commercial fields were surveyed in NW MN, respectively (**Table 1**). Among the randomly surveyed fields there were also 3 known non-Bt fields in 2017, 21 in 2018, 36 in 2019, 8 in 2020, 29 in 2021 and 18 in 2022. The data presented in Table 1 summarize the per plant average number of ECB larvae in surveyed fields by year and Bt status. In 1995, before the 1996 release of ECB Bt hybrids, an average of 1.16 ECB larvae per plant were found in NW MN corn plants. In 2017 through 2019, randomly surveyed corn fields (likely a mix of Bt and non-Bt fields) had an average of 0 to 0.020 larvae per plant, while the average number of larvae per plant in non-Bt corn fields ranged from 0.0190 to 0.1472 larvae per plant. When compared to randomly surveyed fields, in 2017 there were more than 3.3 times the number of larvae per plant in the non-Bt fields; similarly, when compared to randomly surveyed fields, in 2019 there were more than 14 times the number of larvae per plant in the non-Bt fields.

ECB population densities were very low in all surveyed fields in 2020 through 2022. This may indicate that, even though overall ECB populations are low, they still follow the historical cycle entomologists believe is related to a fungal disease and other parasites causing dramatic declines in high ECB populations every 6-7 years. An additional factor that might have impacted population densities of larvae within plants, is the historic extreme drought conditions that prevailed in NW MN in 2021, as mortality of both eggs and early larval instars has been associated with uninterrupted periods of hot, dry weather. Another key factor is likely the high Bt use rates in NW MN.

For Additional Information: Angie Peltier, Anthony Hanson, Ryan Miller, Bruce Potter, Dean Malvick & Bill Hutchison

Project Funding Provided by:
Minnesota Corn Research and Promotion Council

Table 1. NW MN crop reporting district data for ECB larvae and percentage of fields infested in field corn, Minnesota 2017-22. Baseline data for 1995, prior to Bt corn commercialization is also shown (non-Bt fields)*

	Mean #ECB larvae/plant (n)		Fields Infested (%)
Year	Random fields	Known non-Bt fields only	All fields (Only non-Bt fields)
1995	1.16*	1.16*	. (.)
2017	0.0200 (10)	0.0667 (3)	15.4 (33.3)
2018	0.0000 (9)	0.0190 (21)	10.0 (14.3)
2019	0.0105 (19)	0.1472 (36)	25.5 (33.3)
2020	0.0000 (20)	0.0000 (8)	0.0 (0.0)
2021	0.0000 (14)	0.0344 (29)	9.3 (13.8)
2022	0.0000 (20)	0.0000 (18)	0.0 (0.0)

It is interesting to note that among the non-Bt fields sampled in 2020-2022, only 0.0 to 9.3 percent were infested with one or more larvae. This trend continues to indicate that the “halo effect” of Bt corn protection is still active in protecting non-Bt fields from ECB (Hutchison, unpublished data). Briefly, the halo effect is attributed to ECB moth dispersal and behavior, where the number of moths dispersing out of non-Bt fields each spring/summer is greater than moths immigrating back to non-Bt fields. Thus, fewer eggs are laid in non-Bt corn. Because ECB moths cannot distinguish between Bt and non-Bt fields, the majority of eggs will be laid in Bt fields (via current high Bt use), and virtually all larvae emerging in Bt fields will die (assuming ECB remains susceptible to Bt). While higher than the number of larvae per plant in fields surveyed at random, the average number of larvae per plant in non-Bt fields is much lower than the traditional economic threshold levels for ECB (typically estimated at 0.5 larvae/plant).

Bottom line.

While this information provides a ‘30,000 ft view’ of ECB in the region, remember that these are region-wide averages and do not replace scouting of individual fields for making informed, in-season pest management decisions. One positive for those planting non-Bt corn in NW MN, the larvae collected in this region reflect the single-generation type of ECB, meaning that scouting and insecticide management can be confined to a shorter time each year.

Each farmer has a different tolerance for risk. While low populations mean that there is less risk associated with planting corn hybrids without Bt for ECB protection, the risk is not zero, and varies from year to year.

Want to learn more?

For additional information about the European corn borer and ECB management, visit:

https://extension.umn.edu/corn-pest-management/european-corn-borer-minnesota-field-corn

For Additional Information: Angie Peltier, Anthony Hanson, Ryan Miller, Bruce Potter, Dean Malvick and Bill Hutchison

Project Funding Provided by: Minnesota Corn Research and Promotion Council

Farmer-driven Research into Planting Green along the Red

Farm fields near Town, County: Gentilly, Polk; Browns Valley, Traverse; Tintah, Traverse; Barrett, Grant; Appleton, Swift.

Experimental Design: Treatments arranged as large strips wide enough to accommodate farmer's equipment in a randomized complete block design with three replications. While nutrient cycling & soil health data were also collected, here are reported rye biomass at termination, soybean stand count, yield, moisture & test weight data.

Treatments: 1) Current tillage practice without a fall-seeded cereal rye cover crop (CC), 2) CC terminated (term.) with glyphosate 1-2 weeks before soybean planting, 3) CC term. at planting, or CC term. 1-2 weeks after soybean planting.

Purpose of Study:

Minnesota (MN) farmers face difficult choices when deciding to prioritize either long-term soil health goals or the immediate benefits of tillage for residue management and seedbed preparation. Despite the reported soil health benefits of cover crops, a short growing season makes delays to spring field work risky. Research on cover cropping suggests that early season cover crops can stabilize yields by mitigating excess and limited soil moisture, improving field trafficability, and reducing wind erosion. Reliable advice on agronomic outcomes of cover cropping is critically needed by MN farmers interested in adopting reduced-tillage and cover cropping systems. To meet this need, we partnered with MN farmers to design 5 replicated, production-scale research and demonstration trials that were sown to cereal rye in *Fall 2021* (**Fig. 1, Table 1**). Soybeans were seeded in spring 2022 and cover crops terminated before, at or after soybean planting.

Here we summarize the effect of cover crop termination timing on rye biomass, soybean stand count and seed moisture, test weight and yield.

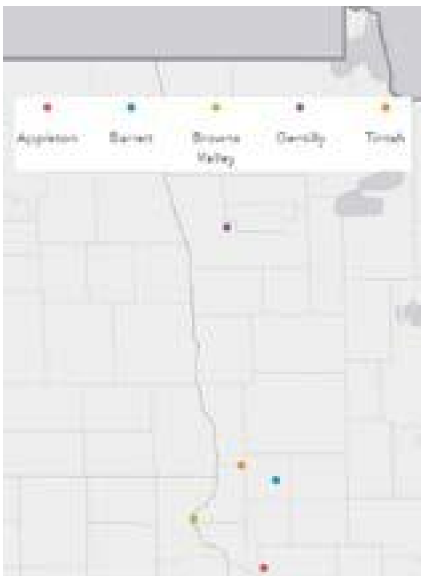

Fig. 1. On-farm trial locations in 2021-2022.

Results:

Table 1. Dates that the 2021 winter rye cover and 2022 soybean crop were seeded and soybean seeding rate in five Minnesota farm fields

Town	Rye seed-ed ('21)	Soybean seeded ('22)	Soybean seeding rate (per acre)
Appleton	Oct 30-31	May 10	140,000
Browns Valley	Oct 31	May 23	165,000
Tintah	Sep 8	Jun 8	140,000
Barrett	Oct 31	May 27	165,000
Gentilly	Sep 7	Jun 7	175,000

Each trial location grew different soybean varieties and had a different soybean seeding dates and rates and therefore different dates of rye termination and so results are presented by location.

Browns Valley. Aerial seeding of rye into a standing silage corn crop in the fall of 2021 allowed some seed to drift into the no-rye plots (**Table 2**). The before-planting and no-rye plots had similar biomass, the at-planting treatment accumulated 245 lb/A more biomass and after-planting still an additional 125 lb/A biomass.

There was a numerical trend with the lower rye biomass the greater the soybean stand count, with the after-planting rye termination averaging 21,511 fewer plants/A than the other treatments.

Soybean yields were similar for all but the lower yielding after-planting rye termination timing. Soybean moisture and test weights were similar among treatments.

Tintah. Termination timing had a significant effect on rye biomass, with greater biomass with each successive timing (**Table 3**). The no-rye and before-planting termination timing treatments had significantly higher soybean stand counts than the plots in which rye was terminated at or after soybean planting.

The yields in the no-rye or before-planting termination timing plots were similar and greater than when rye was terminated at planting. Yield was lowest when rye termination took place after soybean planting. Oddly, soybean test weights were…..

For additional information, contact: Angie Peltier (apeltier@umn.edu) & Jodi DeJong-Hughes (dejon003@umn.edu), UMN Extension; Anna Cates, Lindsay Pease, Peyton Loss & Kat LaBine, UMN Dept. of Soil Water & Climate; Melissa Carlson & Chris Matter, MN Wheat Research & Promotion Council; Dorian Gatchell, MN Ag Services.

Project funding provided by: Minnesota Soybean Research & Promotion Council
Minnesota Wheat Research & Promotion Council.

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….. significantly lower in plots with no rye or when rye was terminated before planting than when rye was terminated at planting.

Table 2. The effect of rye termination timing on rye biomass, soybean stand count, yield, moisture and test weight at the farm near Browns Valley, MN

Rye termination timing	Rye biomass (lb/A)	Soybean stand count (plants/A)	Yield (bu/A)	Moisture (%)	Test weight (lb/bu)
Before planting	116 a	104,221 b	41.7 b	11.6	57.7
At planting	351 b	103,576 b	41.2 b	11.6	57.7
After planting	476 c	83,248 a	34.5 a	11.6	47.3
No rye	97 a	106,480 b	39.4 b	11.7	57.20
LSD (90% CL)	53	10,492	2.61	NS	NS
CV (%)	16.15	6.65	4.19	0.81	15.76

Table 3. The effect of rye termination timing on rye biomass, soybean stand count, yield, moisture and test weight at the farm near Tintah, MN

Rye termination timing	Rye biomass (lb/A)	Soybean stand count (plants/A)	Yield (bu/A)	Moisture (%)	Test weight (lb/bu)
Before planting	154 a	111,320 b	44.4 c	10.8	58.4 a
At planting	383 b	95,040 a	40.0 b	10.7	59.3 b
After planting	515 c	87,560 a	36.5 a	10.9	59.0 ab
No rye		109,120 b	45.6 c	10.8	58.3 a
LSD (90% CL)	71	11,257	1.60	NS	0.71
CV (%)	13.18	7.04	2.42	0.99	0.70

Barrett. Rye biomass was significantly lower when terminated before soybean, than when terminated either at or after soybean planting (**Table 4**). Soybean stand did not differ among treatments.

Soybean yield was statistically similar regardless of rye termination timing, and lower than when grown without the rye cover crop. Soybean moisture was lowest in plots in which rye was terminated after soybean planting and highest in plots without rye or when rye was terminated before soybean planting.

Gentilly. The exceptional drought and early wheat harvest in 2021 allowed for timely rye seeding and the abnormally wet 2022 spring led to delayed soybean planting at the northernmost location (the farm near Gentilly) allowing considerable rye growth.

Each successive rye termination timing allowed for significantly more biomass to accumulate when compared to the previous timing (**Table 5**). Rye biomass was perhaps responsible for the lower soybean stand count, the greater the biomass accummulation, and significantly lower stands in the plots in which rye was terminated at or after soybean planting.

Surprisingly, soybean yields were statistically similar and greater in the plots with no-rye, at-planting and after-planting rye termination treatments than in the plots in which rye was terminated before planting. Soybean moisture content was significantly similar and higher in the rye plots than in the no-rye plots. Soybean test weight was significantly higher in the plots in which rye was terminated after-planting than at-planting.

Table 4. The effect of rye termination timing on rye biomass, soybean stand count, yield, moisture and test weight at a farm near Barrett, MN

Rye termination timing	Rye biomass (lb/A)	Soybean stand count (plants/A)	Yield (bu/A)	Moisture (%)	Test weight (lb/bu)
Before planting	126 a	130,357	45.9 a	10.8 b	57.3
At planting	250 b	128,421	46.9 a	10.7 ab	57.2
After planting	299 b	139,392	45.3 a	10.6 a	56.7
No rye		147,781	54.9 b	10.8 b	56.8
LSD (90% CL)	66	NS	3.1	0.2	NS
CV (%)	17.71	9.35	4.5	1.27	0.64

Table 5. The effect of rye termination timing on rye biomass, soybean stand count, yield, moisture and test weight at a farm near Gentilly, MN

Rye termination timing	Rye biomass (lb/A)	Soybean stand count (plants/A)	Yield (bu/A)	Moisture (%)	Test weight (lb/bu)
Before planting	231 a	196,698 ab	35.7 a	12.2 b	60.7 ab
At planting	387 b	175,015 a	41.4 b	12.5 b	60.2 a
After planting	501 c	168,045 a	40.9 b	12.5 b	60.9 b
No rye		215,283 b	44.2 b	11.5 a	60.8 ab
LSD (90% CL)	107	29,186	4.9	0.6	0.7
CV (%)	38.74	9.75	7.63	2.85	0.77

Appleton. The first rye termination at the near Appleton took place at soybean planting. A significant additional 105 lb/A of rye biomass were added in the 13 days between soybean planting and the after-planting termination timing (**Table 6**). A numerical trend was ….

For additional information, contact: Angie Peltier (apeltier@umn.edu) & Jodi DeJong-Hughes (dejon003@umn.edu), UMN Extension; Anna Cates, Lindsay Pease, Peyton Loss & Kat LaBine, UMN Dept. of Soil Water & Climate; Melissa Carlson & Chris Matter, MN Wheat Research & Promotion Council; Dorian Gatchell, MN Ag Services.

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….observed in that the greater the greater the cover crop biomass, the lower the soybean stand count. But this slight trend did not result in any statistical differences among treatments for soybean yield, moisture and test weight.

Table 5. The effect of rye termination timing on rye biomass, soybean stand count, yield, moisture and test weight at a farm near Appleton, MN

Rye termination timing	Rye biomass (lb/A)	Soybean stand count (plants/A)	Yield (bu/A)	Moisture (%)	Test weight (lb/bu)
Before planting	Treatment not included at this location				
At planting	55 a	115,837	39.9	10.9	56.2
After planting	160 b	114,869	36.8	10.5	56.9
No rye		116,483	46.4	10.0	55.9
LSD (90% CL)		NS	NS	NS	NS
CV (%)	30.86	1.70	10.64	8.13	1.74

Summary. This document summarizes crops grown in farmer cooperators' fields in two abnormal growing seasons. The rye cover crop was seeded after an abnormally early harvest of the 2021 wheat crop (Gentilly) due to exceptional drought conditions or into standing corn crops (Barrett, Browns Valley, Tintah, Appleton) and then in spring 2022, soybean was seeded a month (or greater) later than normal due to very wet soil conditions. Only time will reveal how 'typical' the results of this 2021-22 study were.

Rye biomass & soybean stand count. Delaying cover crop termination until 1-2 weeks after soybean planting produced more cover crop biomass; at four of the five trial locations, there was significantly more biomass with this delayed termination. However, at most of the locations, planting soybean into a living cover crop that was then terminated either immediately after planting or numerically lower soybean stand counts when compared to soybeans grown in plots in which the rye was terminated before planting or in plots without rye (**Figure 1**).

Soybean yield, moisture & test weight. At one location, there were no differences in yield among cover crops treatments; at another, all of the treatment yields were similar with the surprising exception of lower yield in plots terminated before soybean planting. At two locations, regardless of termination timing rye plots yielded significantly less than the no-rye plots. In another location, yield in the no-rye plots was statistically similar to yield in rye plots terminated before soybean planting, with each later termination timing yielding significantly less than plots of earlier termination timing.

Soybean moisture and test weight were not affected by cover crops treatments at 3 of the trial locations. At one location soybean moisture was higher when a cover crop was grown than when not; at another, soybean moisture was lower in rye plots that were terminated after planting than in the no rye or other rye termination timings. At one location test weight was higher and at another lower when rye was terminated at planting.

Stay tuned. Watch for news about this project as additional tests are currently being run and data analyzed. Look for more research results on the effects of different combinations of cover crop seeding rate, tillage strategies and cover crop termination timing on nutrient cycling, soil health metrics, iron deficiency chlorosis and weed management at the UMN Research & Outreach Centers (ROC) in Crookston and Morris, MN.

In fall 2022, rye was seeded at 3 on-farm locations surrounding each of the two ROCs in anticipation of planting soybean "green" for further study in 2023. This project will run both on ROCs and on cooperators' farms through 2025.

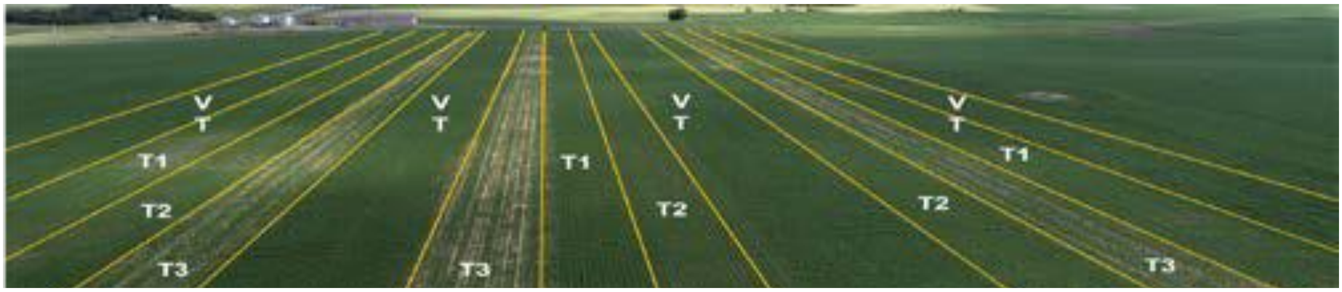

Figure 1. One can see the effects of cover crop termination timing on soybean stand at the Barrett field location. Plot edges are delineated by lines and the before, at and after soybean seeding are labeled T1, T2 and T3, respectively. Vertical tillage plots without a cover crop are labeled VT. (Photo: Dorian Gatchell & Jodi DeJong-Hughes)

For additional information, contact: Angie Peltier (apeltier@umn.edu) & Jodi DeJong-Hughes (dejon003@umn.edu), UMN Extension; Anna Cates, Lindsay Pease, Peyton Loss & Kat LaBine, UMN Dept. of Soil Water & Climate; Melissa Carlson & Chris Matter, MN Wheat Research & Promotion Council; Dorian Gatchell, MN Ag Services.

Managing Volunteer Corn in 2,4-D Tolerant Soybeans — Olmsted and Waseca Counties, MN

Cooperator: University of Minnesota Extension

Nearest Town: Waseca and Rochester
Soil Type: Clay loam and loam
Tillage: Conventional
Previous Crop: Corn
Planting Date: Waseca: 05/28/2022 Rochester: 06/02/2022
Spray Dates: Waseca: POST I 06/28/2022 POST II: 07/05/2022
Rochester: POST I 07/01/2022 POST II 07/09/2022
Variety: Stine 19EC12
Row Width: 30 inch
Harvest Population: 150,000
Experimental Design: Randomized complete block with 4 replications

For Additional Information:
Ryan Miller, mill0869@umn.edu

Project Funding Provided by:
Minnesota Soybean and Research and Promotion Council

Purpose of Study:
Soybean varieties tolerant to 2,4-D-choline, glyphosate, and glufosinate have been widely adopted by Minnesota soybean growers. While 2,4-D tolerant soybeans provide growers with another site of action to manage glyphosate-resistant weed populations, there has also been difficulty in achieving adequate control of volunteer corn in this system. ACCase-inhibiting herbicides are often the primary tool for managing volunteer corn and the ACCase-inhibiting herbicides when tank mixed with auxinic herbicides showed antagonism and resulted in reduced control of grassy weeds. Growers relying on previously effective herbicide rates and application strategies are often surprised when they do not achieve adequate volunteer corn control. The objective of this research was to evaluate the interaction between ACCase-inhibiting herbicides (clethodim and quizalofop-ethyl) and 2,4-D choline alone or tank-mixed with glyphosate or S-metolachlor for glyphosate-resistant volunteer corn control in 2,4-D tolerant soybean.

Results:
Generally, lower rates of either volunteer corn controlling graminicide resulted in reduced volunteer corn control, although reduced control was more pronounced with quizalofop-ethyl (Assure II) treatments. Higher graminicide rates helped overcome the antagonism between ACCase-inhibiting herbicides and 2,4-D choline and could be a useful strategy for managing volunteer corn. Sequential applications of quizalofop-ethyl (Assure II) provided better control of volunteer corn. Glyphosate did not appear to cause any antagonism.

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Preliminary Data 11/17/2022, final report will be available by 11/30/2022

TREATMENTS

•**PREEMERGENCE**
•All treatments have a preemergence Dual II Magnum

•**POSTEMERGENCE**
1.UNTREATED
2.Enlist + Glyphosate + Select Max 6 oz + (AMS & NIS)
3.Enlist + Glyphosate + Select Max 6 oz + Dual + (AMS & NIS)
4.Enlist + Glyphosate + Select Max 9 oz + (AMS & NIS)
5.Enlist + Glyphosate + Select Max 9 oz + Dual + (AMS & NIS)
6.Enlist + Select Max 6 oz + (AMS & COC)
7.Enlist + Select Max 6 oz + Dual + (AMS & COC)
8.Enlist + Select Max 9 oz + (AMS & COC)
9.Enlist + Select Max 9 oz + Dual + (AMS & COC)
10.Enlist + Glyphosate + Assure II 4 oz + (AMS & COC)
11.Enlist + Glyphosate + Assure II 4 oz + Dual + (AMS & COC)
12.Enlist + Glyphosate + Assure II 12 oz + (AMS & COC)
13.Enlist + Glyphosate + Assure II 12 oz + Dual + (AMS & COC)
14.Enlist + Assure II 4 oz + (AMS & COC)
15.Enlist + Assure II 4 oz + Dual + (AMS & COC)
16.Enlist + Assure II 12 oz + (AMS & COC)
17.Enlist + Assure II 12 oz + Dual + (AMS & COC)
18.Enlist + Glyphosate+ (AMS) fb1 Select Max 6 oz + (COC & AMS)
19.Enlist + Glyphosate + (AMS) fb Assure II 4 oz + (COC & AMS)
20.WEED FREE

*1= graminicide in a sequential treatment 5-7 days after initial POST treatment
COC = SuperbHC®
NIS = Preference®

For Additional Information:
Ryan Miller, mill0869@umn.edu

Preliminary Data 11/17/2022, final report will be available by 11/30/2022

Rochester Data August 5th rating date, Percent Volunteer Corn Control

Trt No.	Treatment Name	Rate Rate Unit	Appl Code	volunteer corn Aug-5-2022 12"
1	UNTREATED			0.0e
2	Enlist One	2pt/a	A	90.8ab
	PowerMax 3	30fl oz/a	A	
	Select Max	6fl oz/a	A	
	Amsol	3qt/a	A	
	NIS	0.25% v/v	A	
3	Enlist One	2pt/a	A	83.0b
	PowerMax 3	30fl oz/a	A	
	Select Max	6fl oz/a	A	
	Dual Magnum	1pt/a	A	
	Amsol	3qt/a	A	
	NIS	0.25% v/v	A	
4	Enlist One	2pt/a	A	93.5a
	PowerMax 3	30fl oz/a	A	
	Select Max	9fl oz/a	A	
	Amsol	3qt/a	A	
	NIS	0.25% v/v	A	
5	Enlist One	2pt/a	A	93.0a
	PowerMax 3	30fl oz/a	A	
	Select Max	9fl oz/a	A	
	Dual Magnum	1pt/a	A	
	Amsol	3qt/a	A	
	NIS	0.25% v/v	A	
6	Enlist One	2pt/a	A	92.3a
	Select Max	6fl oz/a	A	
	Amsol	3qt/a	A	
	COC	1qt/a	A	
7	Enlist One	2pt/a	A	91.8ab
	Select Max	6fl oz/a	A	
	Dual Magnum	1pt/a	A	
	Amsol	3qt/a	A	
	COC	1qt/a	A	
8	Enlist One	2pt/a	A	97.5a
	Select Max	9fl oz/a	A	
	Amsol	3qt/a	A	
	COC	1qt/a	A	
9	Enlist One	2pt/a	A	96.3a
	Select Max	9fl oz/a	A	
	Dual Magnum	1pt/a	A	
	Amsol	3qt/a	A	
	COC	1qt/a	A	
10	Enlist One	2pt/a	A	31.3c
	PowerMax 3	30fl oz/a	A	
	Assure II	4fl oz/a	A	
	Amsol	3qt/a	A	
	COC	1qt/a	A	
11	Enlist One	2pt/a	A	15.0d
	PowerMax 3	30fl oz/a	A	
	Assure II	4fl oz/a	A	
	Dual Magnum	1pt/a	A	
	Amsol	3qt/a	A	
	COC	1qt/a	A	
12	Enlist One	2pt/a	A	94.5a
	PowerMax 3	30fl oz/a	A	
	Assure II	12fl oz/a	A	
	Amsol	3qt/a	A	
	COC	1qt/a	A	
13	Enlist One	2pt/a	A	97.0a
	PowerMax 3	30fl oz/a	A	
	Assure II	12fl oz/a	A	
	Dual Magnum	1pt/a	A	
	Amsol	3qt/a	A	
	COC	1qt/a	A	
14	Enlist One	2pt/a	A	10.0d
	Assure II	4fl oz/a	A	
	Amsol	3qt/a	A	
	COC	1qt/a	A	
15	Enlist One	2pt/a	A	6.3de
	Assure II	4fl oz/a	A	
	Dual Magnum	1pt/a	A	
	Amsol	3qt/a	A	
	COC	1qt/a	A	
16	Enlist One	2pt/a	A	95.3a
	Assure II	12fl oz/a	A	
	Amsol	3qt/a	A	
	COC	1qt/a	A	
17	Enlist One	2pt/a	A	97.0a
	Assure II	12fl oz/a	A	
	Dual Magnum	1pt/a	A	
	Amsol	3qt/a	A	
	COC	1qt/a	A	
18	Enlist One	2pt/a	A	96.0a
	PowerMax 3	30fl oz/a	A	
	Amsol	2.5% v/v	A	
	Select Max	6fl oz/a	B	
	Amsol	3qt/a	B	
	COC	1qt/a	B	
19	Enlist One	2pt/a	A	98.0a
	PowerMax 3	30fl oz/a	A	
	Amsol	2.5% v/v	A	
	Assure II	4fl oz/a	B	
	Amsol	3qt/a	B	
	COC	1qt/a	B	
20	WEED FREE			99.0a

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Continued on next page

Preliminary Data 11/17/2022, final report will be available by 11/30/2022

Waseca Data August 3rd rating date, Percent Volunteer Corn Control

Trt No.	Treatment Name	Rate Rate Unit	Appl Code	VC Aug-3-2022 10"
1	UNTREATED			0.0i
2	Enlist One	2pt/a	A	91.0cde
	PowerMax 3	30fl oz/a	A	
	Select Max	6fl oz/a	A	
	Amsol	3qt/a	A	
	NIS	0.25% v/v	A	
3	Enlist One	2pt/a	A	88.8e
	PowerMax 3	30fl oz/a	A	
	Select Max	6fl oz/a	A	
	Dual Magnum	1pt/a	A	
	Amsol	3qt/a	A	
	NIS	0.25% v/v	A	
4	Enlist One	2pt/a	A	99.0a
	PowerMax 3	30fl oz/a	A	
	Select Max	9fl oz/a	A	
	Amsol	3qt/a	A	
	NIS	0.25% v/v	A	
5	Enlist One	2pt/a	A	97.0ab
	PowerMax 3	30fl oz/a	A	
	Select Max	9fl oz/a	A	
	Dual Magnum	1pt/a	A	
	Amsol	3qt/a	A	
	NIS	0.25% v/v	A	
6	Enlist One	2pt/a	A	92.5b-e
	Select Max	6fl oz/a	A	
	Amsol	3qt/a	A	
	COC	1qt/a	A	
7	Enlist One	2pt/a	A	92.3b-e
	Select Max	6fl oz/a	A	
	Dual Magnum	1pt/a	A	
	Amsol	3qt/a	A	
	COC	1qt/a	A	
8	Enlist One	2pt/a	A	99.0a
	Select Max	9fl oz/a	A	
	Amsol	3qt/a	A	
	COC	1qt/a	A	
9	Enlist One	2pt/a	A	98.0a
	Select Max	9fl oz/a	A	
	Dual Magnum	1pt/a	A	
	Amsol	3qt/a	A	
	COC	1qt/a	A	
10	Enlist One	2pt/a	A	11.3g
	PowerMax 3	30fl oz/a	A	
	Assure II	4fl oz/a	A	
	Amsol	3qt/a	A	
	COC	1qt/a	A	
11	Enlist One	2pt/a	A	13.8g
	PowerMax 3	30fl oz/a	A	
	Assure II	4fl oz/a	A	
	Dual Magnum	1pt/a	A	
	Amsol	3qt/a	A	
	COC	1qt/a	A	
12	Enlist One	2pt/a	A	91.0cde
	PowerMax 3	30fl oz/a	A	
	Assure II	12fl oz/a	A	
	Amsol	3qt/a	A	
	COC	1qt/a	A	
13	Enlist One	2pt/a	A	95.3abc
	PowerMax 3	30fl oz/a	A	
	Assure II	12fl oz/a	A	
	Dual Magnum	1pt/a	A	
	Amsol	3qt/a	A	
	COC	1qt/a	A	
14	Enlist One	2pt/a	A	6.3h
	Assure II	4fl oz/a	A	
	Amsol	3qt/a	A	
	COC	1qt/a	A	
15	Enlist One	2pt/a	A	3.8hi
	Assure II	4fl oz/a	A	
	Dual Magnum	1pt/a	A	
	Amsol	3qt/a	A	
	COC	1qt/a	A	
16	Enlist One	2pt/a	A	61.3f
	Assure II	12fl oz/a	A	
	Amsol	3qt/a	A	
	COC	1qt/a	A	
17	Enlist One	2pt/a	A	88.7e
	Assure II	12fl oz/a	A	
	Dual Magnum	1pt/a	A	
	Amsol	3qt/a	A	
	COC	1qt/a	A	
18	Enlist One	2pt/a	A	90.0de
	PowerMax 3	30fl oz/a	A	
	Amsol	2.5% v/v	A	
	Select Max	6fl oz/a	B	
	Amsol	3qt/a	B	
	COC	1qt/a	B	
19	Enlist One	2pt/a	A	94.3a-d
	PowerMax 3	30fl oz/a	A	
	Amsol	2.5% v/v	A	
	Assure II	4fl oz/a	B	
	Amsol	3qt/a	B	
	COC	1qt/a	B	
20	WEED FREE			99.0a

For Additional Information:
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Photos of what antagonism looked like (4oz of Assure II in tank mix vs. 4 oz of Assure II applied sequentially):

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Corn stalk rot survey – 2022: Northwest Minnesota

Cooperators: Personnel visited fields of cooperating producers in Becker, Clay, Kittson, Mahnomen, Marshall, Norman, Pennington, Polk, Red Lake and Roseau Counties.

Purpose of Study:
During a fall survey of 38 corn fields in Becker, Beltrami, Clay, Kittson, Mahnomen, Marshall, Norman, Pennington, Polk, Red Lake and Roseau counties in NW MN for European corn borer, personnel also assessed stalk strength using a "standard" push-test. Briefly, 50 random plants in each field were pushed at ear height more than 30 degrees from vertical. Plants 'failed' this test by permanently bending or breaking and not returning upright, indicating poor stalk strength.

This survey was not designed to differentiate between stalk quality issues caused by disease or other stressors but rather to assess standability of the 2022 corn crop.

Results:
Developing corn kernels place a high demand on the plant for sugars. Stress slows photosynthesis, reducing the amount of sugar the plant can produce. Different stresses can reduce the rate of photosynthesis: too much or too little moisture, nutrient imbalances, plant injury (ex.: hail, insects, diseases), excessive plant populations, and even long-periods of cloudy weather.

Hybrid genetics and/or high yield potential combined with stress during grain fill can increase the probability of stalk quality issues. Stalk quality tends to decrease the longer the crop remains in the field unharvested.

If a plant is unable to keep up with kernel sugar demand, it can rob sugars from stalk tissue, deteriorating stalk integrity and predisposing it to stalk rotting fungi.

In NW MN, the percentage of plants suffering from stalk rot ranged from a low of 0 percent (6 fields) to a high of 36 percent (1 field; **Figures 1 and 2**); 39% of the fields had stalk quality issues that might have impacted harvestability, fewer than the 51% of fields in 2021.

Crop stressors in 2022 included planting into unfit fields or planting later than normal due to excessive spring rains and mild temperatures throughout much of the growing season. Mudding in the crop or too much soil moisture can negatively impact root function and cool temperatures are unconducive for efficient photosynthesis. Slowed photosynthetic rate slows the accumulation of sugars needed for grain-fill, and plants begin mining carbohydrates from stalks to fill kernels, predisposing stalk to pathogen infection.

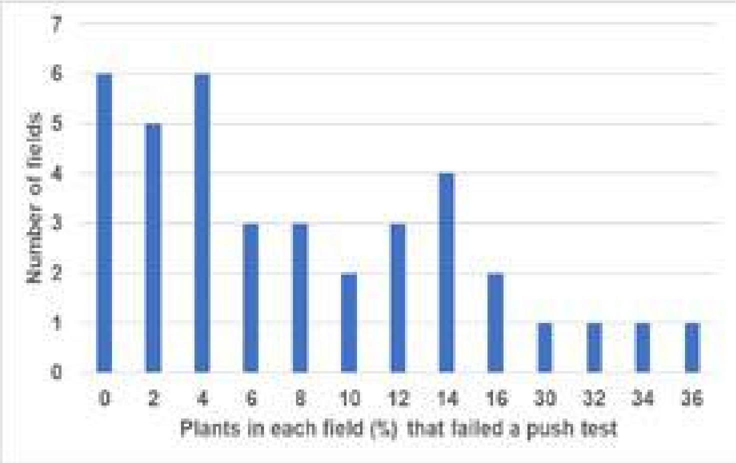


Fig. 1. The percentage of plants failing the push test.

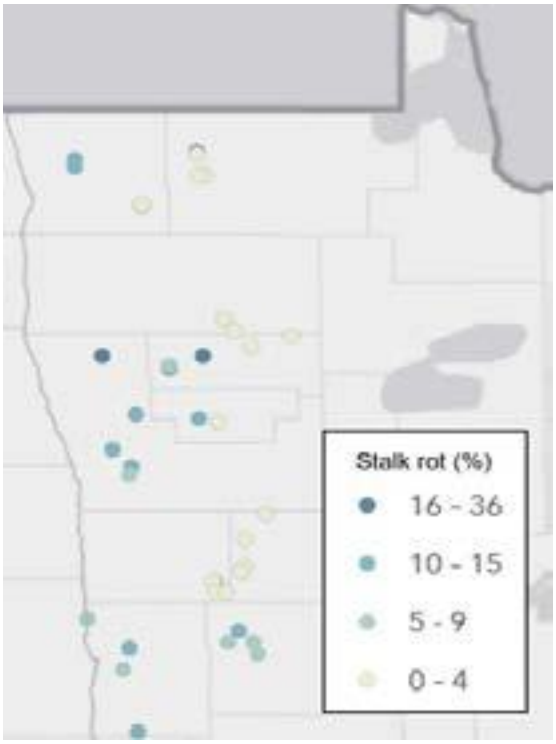


Fig 2. The location of fields surveyed and the percentage of plants failing the push test in 38 fields in 2022.

For Additional Information: Angie Peltier, Anthony Hanson, Ryan Miller, Bruce Potter, Bill Hutchison or Dean Malvick

Project Funding Provided by:
Minnesota Corn Research and Promotion Council

Evaluating soybean varieties to identify genetic and sources of resistance and escape against white mold

Cooperators: Megan McCaghey, Ashish Ranjan (data not shown), Aaron Lorenz, Suma Sreekanta, Hsuan-Fu Wang, Alisha Hershman Wade Webster, Damon Smith

For Additional Information: Megan McCaghey, Ashish Ranjan, or Aaron Lorenz

Project Funding Provided by: Minnesota Soybean Research and Promotion Council

Purpose of Study:
The purpose of this work was to develop tools for white mold resistance breeding and research in Minnesota. White mold is caused by the soilborne fungal pathogen, Sclerotinia sclerotiorum and can cause severe yield losses when conditions are suitable for disease development. One of the most effective means to control white mold is the use of resistant cultivars. This work aimed to characterize Sclerotinia sclerotiorum isolates, collected throughout Minnesota, that can be used to comprehensively screen soybean lines and study fungal biology. We are also working to compare field techniques for infesting research fields to conduct research on white mold management under more consistent disease pressure. Lastly, this project aims to define relationships between canopy architecture and S. sclerotiorum development, to provide another, underexplored consideration for disease resistance breeding white mold. The goals of this work will set the stage for my soilborne fungi pathology lab to conduct biologically relevant SSR research in soybean and will open new, creative avenues to improve resistance to this challenging fungal disease.

Results:
PROJECT OBJECTIVES:
1. GOAL: Characterize the aggressiveness of S. sclerotiorum isolates for use in future pathogen biology and resistance screening assays

This study aims to characterize Minnesota isolates in soybean to establish a range of native, biologically relevant isolates for germplasm screening and fungal biology assays in Minnesota. So far, we have developed an isolate collection of 22 isolates. These isolates have been collected mostly from the Northwestern part of Minnesota (near Crookston). Isolates were surface sterilized using 10% bleach and 70% ethanol solutions. They were then plated, bulked on carrots and stored.

In our preliminary screenings, seven isolates of S. sclerotiorum were evaluated for their aggressiveness as indicated by lesion size on soybean over time. An “empty plug” of agar with no fungus was used as a control to show that lesions were caused by the fungus, not cutting of the petiole. Three plants were inoculated in a single pot and five pots were inoculated per isolate (15 plants per isolate) at the V4 growth stage. The treatments were arranged in a randomized complete block design in the growth chamber. Lesions were measured at 24, 96, and 120 hours post inoculation (HPI). Screenings will continue through the fall and winter. Consistent lesions formed on plants and allowed the isolates to be compared. Results of the initial screening indicated differing levels of aggressiveness per isolate (Figure 1). For example, MNSS4 P (light blue) appears to be less aggressive than MNSS4 V (bright pink).

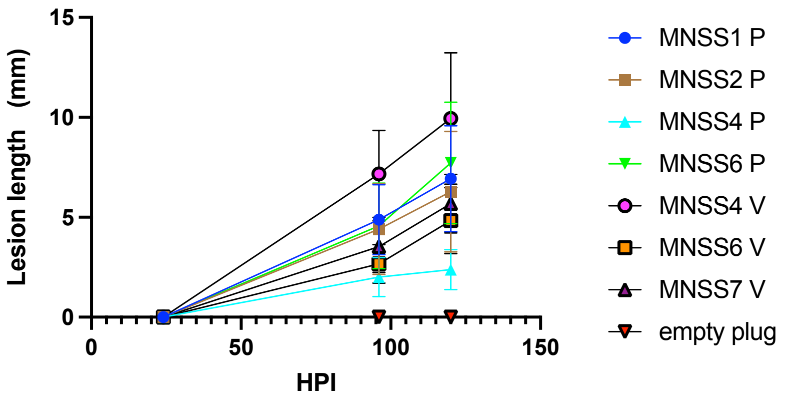


Figure 1. Lesion size on soybean at 24, 96, and 120 hrs after being inoculated (HPI) with seven isolates of S. sclerotiorum. Graph provided by new graduate student, Hsuan-Fu Wang.

Continued on next page

Once we identify a panel of isolates with different levels of aggressiveness, we can test whether isolates will distinguish the resistance ranking of cultivars. Using three representative isolates, we will inoculate soybean check lines developed by Dr. Damon Smith's Lab at University of Wisconsin, Madison with known low, moderate, and high levels of resistance (compared to susceptible controls) to see if resistance rankings are similar when challenged with the new, UMN isolates and whether our isolate panel can differentiate putative resistant from susceptible lines.

2. GOAL : Define relationship between canopy architecture and SSR development

In addition to physiological resistance, plant architecture may be an important for avoiding soybean infection by S. sclerotiorum in the field. Apothecia (the mushrooms required for infection of the pathogen) production is influenced by moisture and light (quality and quantity)

Light detection under the soybean canopy with a UVB meter

The Lorenz Lab planted soybean panels (of diverse plant architectures) in Waseca on 5/16/22 and in St. Paul on 6/8/2022. In total, we are evaluating three trials, in both Waseca and St. Paul. Suma Sreekanta, the postdoctoral researcher in the Lorenz Lab, is collecting data on various phenotypic traits that impact light penetration to the ground (where apothecia form) including branch angle, branch number, canopy coverage, and leaf area. Drone data for canopy coverage has been underway once or twice a week since planting.

We scouted for apothecia in each row of soybeans using a t-shaped PVC push pole prior to flowering (in St. Paul) and at early flowering stages (Waseca) through canopy closure, when apothecia begin to develop. The plots were checked in St. Paul on 7/13/2022, 7/22/2022, 7/27/2022, 8/4/2022, and 8/16/2022. We scouted for apothecia in Waseca on 8/2/2022, and 8/17/2022. No apothecia were observed. We also conducted disease assessments at the R6, full pod growth stage. In Waseca, disease assessments were conducted on 8/17/2022 and we saw no white mold. We also conducted disease assessments in St. Paul on 9/13/22 but only had only one plot with disease pressure. The lack of apothecia and disease is likely related to the drought experienced earlier in the summer, and we anticipate that our data collection will be improved with white mold nurseries in the future (Goal 3).

We collected light measurements using a UVB meter in St. Paul starting at beginning flowering, the time most important for Sclerotinia infection, and through canopy closure on 7/22/2022, 7/28/2022, and 8/4/2022. UVB captures that spectrum of wavelengths considered to be the most important for apothecia production. Measurements were conducted in the morning on days with no cloud cover that might block the UVB penetration to the ground. Measurements were captured in the center of each two rows at 0", 7.5", and 15" from the base of the plant. Comparisons of light conditions under the architecturally diverse lines will be made along with phenotypic comparisons that may contribute to white mold development this fall.

Based on phenotypic data, we will narrow down the number of lines to a panel with a range of the traits measured. We will inoculate them with S. sclerotiorum in the greenhouse and compare their genetic resistance based on lesion progression over time.

3. GOAL: Develop reliable S. sclerotiorum nurseries for future SSR field trials

Currently, researchers do not have field sites with reliable and uniform inoculum where we can conduct white mold experiments (personal communication). High disease pressure, across plots is often required to observe the impact of experimental treatments (such as variety resistance differences or fungicide efficacy).

This summer, we initiated a trial comparing three methods to encourage uniform disease pressure for trials in 2023. These include 1) growing sunflowers, which are susceptible to white mold, inoculating them the back of the head with a slurry of S. sclerotiorum, and then incorporating residue into the soil in the fall of 2022. We also added 2) sclerotia inoculum generated in the lab on carrot seed into the field during the fall before 2023 trials. Cold conditioning over the winter should allow the inoculum to produce apothecia in the following field season. In the third method, 3) we are growing sclerotia in the lab, cold conditioning them in the fridge, and then will spring apply the sclerotia to the field. 4) Untreated, naturally infested plots will be left as controls to compare with plots treated with the described infestation methods.


Sunflower Sclerotinia slurry inoculations in disease nurseries

Towards this objective, plots were planted on 6/3/2022 at The Northwest Research and Outreach Center (NROC) in Crookston, MN. The variety used was an early, Phomopsis and SSR susceptible Nuseed variety, N4HM354. The trial is a randomized complete block design and each treatment is repeated six times. It was planted on 22" row spacing. Rows are 20 feet long and each treatment plot contained six rows. There is a four-foot buffer of untreated buffer between plots to prevent unintended inoculum spread. Five-foot alleys were left on the front and back of rows. These trials are misted during early flowering until beginning dry down to encourage disease development.

We inoculated plots with a slurry of Sclerotinia at full flowering on 8/22/2022. Slurry was a prepared with a mixture of cultures from three isolates. We chose isolates with a range of aggressiveness, based on the results displayed in Table 1. We have also bulked sclerotia on autoclaved carrots and will apply sclerotia in field plots in the fall, to cold condition in the field and in the spring after cold conditioning in the lab refrigerator. We will apply 30 ml of sclerotia per plot.

In 2023, soybean will be evaluated in the plots and their incidence and severity of SSR infections will be compared. Apothecia density will also be monitored. It is expected that this work will allow for more uniform, consistent disease pressure in which to compare the performance of soybean lines and treatments for SSR.

County/Region: 2022 Continued Evaluation of Conventional Variable Rate Herbicide Tank Mixes on Waterhemp Control – Renville County/South Central

Cooperator: Next Gen Ag LLC

Nearest Town: Renville, MN
Soil Type: Webster Clay/4.5% OM/Fine Texture
Tillage: Conventional
Previous Crop: Corn
Plant Date: May 24th, 2022
Variety: Becks 1630E @ 150,000/A
Row Width: 30 Inches
Fertilizer: None Added
Weed Management: Study Objective
Insecticide: Seed Treatment Only
Harvested Population: N/A
Harvested Date: N/A
Experimental Design: RCBD (Randomized-Complete Block Design)

Purpose of Study:
Waterhemp continues to be a challenging weed in farmer fields rapidly developing resistance to multiple modes of action that results in grower continued reliability of genetically engineered herbicide trait resistance. Adding 2, 3, 4, and more trait resistances in soybeans will inevitably result in continued development of waterhemp resistance with no remaining modes of action as adding one herbicide resistant trait into the genetics at a time allows an already resistant population to the previous 3 modes of action plenty of time to develop resistance to a fourth post-emergent mode of action. Residual herbicides are the only way to limit resistance as these products engage the weed at the most vulnerable part of the life cycle (emergence). This study focuses on variable rate tank mixes of conventional residual herbicides with target goals of achieving 95% waterhemp control at a relative cost of $35-$40 per acre. The cost goal was targeted well before the volatile and substantial inflation impact of 2022, so treatments that achieved the cost goal at grant writing in 2021 likely now exceed no longer meeting criteria. A program that combines multiple modes of action and uniformity of use across all genetics.

Results:
1. 2021 Data in Combined Analysis Impacted the A+28 Due to Lack of Early Activating Rain on PRE.
2. 2022 Data had an Early Activating Rain After PRE and 80% of Entries Achieved the 90%+ Threshold with 45% Achieving 95%+.
3. Applying Variable Rate Tank Mixes as a single PRE or two-pass is effective.
4. PRE only VRTM control at A+56 ranged from 87-97% and averaged 92%.
5. PRE fb Layby VRTM control at A+56 ranged from 79-98 and averaged 92%.
6. Best end of season treatments were a result of ONLY Flexstar POST. Flexstar applied alone POST vs. part of PRE tank mix increased control by 3-5%.
7. Treatments are on label, but there are specific guidelines surrounding Valor SX and Warrant tank mixes. This study does not violate those guidelines, but growers should read both product labels to understand the potential risk.
8. After 5 years of evaluating these products across 26 different soybean varieties and 4 companies I have witnessed injury once and crop recovered within a week.
9. Grower's farming soils higher in sand (>33%) and/or lower in %OM (<4.5%) should consider experimenting on the lower end of tank mix rates.

Waterhemp Control from Residual Variable Rate Tank Mixes in Soybean, Renville, MN 2022 & Combined

Treatment[a]	Rate	Waterhemp Control								App. Code
		A+14[b]		A+28		A+42		A+56		
		'22	2YR	'22	2YR	'22	2YR	'22	2YR	
	oz/A* or fl oz/A	------------------%------------------								
Val + War + Zid + Flx[c]	*1.5 + 30 + 3.25 + 7.5	100	100	99	79	88	83	85	87	A
Val + War + Zid / Flx	*1.5 + 30 + 3.25 / 7.5	98	93	100	86	96	91	96	90	A/B
Val + War / Zid + Flx	*1.5 + 30 / 3.25 + 7.5	98	96	100	85	91	93	90	91	A/B
Val + Zid / War + Flx	*1.5 + 3.25 / 30 + 7.5	94	94	99	76	97	92	97	89	A/B
Val / War + Zid + Flx	*1.5 / 30 + 3.25 + 7.5	95	94	90	60	92	90	92	79	A/B
Val + War + Zid + Flx	*2 + 40 + 4 + 10	100	100	99	94	95	96	95	95	A
Val + War + Zid / Flx	*2 + 40 + 4 / 10	98	99	100	83	99	99	98	98	A/B
Val + War / Zid + Flx	*2 + 40 / 4 + 10	93	96	99	74	91	93	89	91	A/B
Val + Zid / War + Flx	*2 + 4 / 40 + 10	96	95	100	76	94	93	93	94	A/B
Val / War + Zid + Flx	*2 / 40 + 4 + 10	93	96	89	66	90	89	89	89	A/B
Blkt + Val + War + Flx	6 + *1.5 + 30 + 7.5	100	100	99	86	89	93	84	89	A
Blkt + Val + War / Flx	6 + *1.5 + 30 / 7.5	98	99	99	74	95	94	93	93	A/B
Blkt + Val / War + Flx	6 + *1.5 / 30 + 7.5	100	94	93	68	93	89	91	89	A/B
Blkt + Val + War + Flx	8 + *2 + 40 + 10	100	100	100	88	91	92	91	92	A
Blkt + Val + War / Flx	8 + *2 + 40 / 10	100	100	100	91	100	99	99	97	A/B
Blkt + Val / War + Flx	8 + *2 / 40 + 10	99	99	100	85	95	95	95	94	A/B
Blkt + Val + War + Flx	10 + *2 + 48 + 12	100	100	98	80	88	92	93	94	A
Blkt + Val + War / Flx	10 + *2 + 48 / 12	100	100	100	95	99	99	99	98	A/B
Blkt + Val / War + Flx	10 + *2 / 48 + 12	100	100	100	89	98	96	97	94	A/B
Blkt+Val+War+Flx+Zid	8 + *2 + 40 + 10 + 3.25	100	100	100	86	100	99	100	97	A
LSD (0.1)		6	6	6	17	7	7	9	9	

[a]PRE treatment applications contained no additional adjuvants; MSO at 0.5% v/v POST.
[b]A+[number]=Days after "A" application.
[c]Flx=Flexstar; War=Warrant; Val=Valor SX; Blkt=Blanket; Zid= Zidua SC equivalent.
COST: Trt 1 thru 5=$35; Trt 6 thru 10=$45; Trt 11 thru 13=$27; Trt 14 thru 16=$36; Trt 17 thru 19=$42; Trt 20=$54.

2022 Western Minnesota Soybean Crop & Pest Survey

Cooperators: Minnesota Soybean Research & Promotion Council, NDSU IPM Survey

Purpose of Study:
The soybean crop and pest survey was designed to provide in-season data about regional pest pressure to assist farmers and consultants in making pest management decisions. The 2022 growing season was the seventh that UMN Extension undertook this MSR&PC-sponsored survey.

This project was coordinated with a similar survey undertaken by the NDSU IPM team. Bi-state survey maps were made by NDSU IPM and are available on the NDSU Pest Management website: https://www.ag.ndsu.edu/ndipm/ipm-survey-archives/

Results:
Field surveys of randomly selected Minnesota soybean fields were initiated on June 20. A total of 514 fields were surveyed from June 20 through August 19 in MN and ND. A total of 109 field visits occurred in Minnesota in 2021. The Minnesota survey locations were fewer than in past years due to difficulty recruiting scouts.

Although the 2022 growing season began approximately 2-4 weeks later than normal, the final growth stages observed in NW MN were similar to those observed in 2021 (**Fig 1**).

Fig 1. Growth stages, Aug 8-19, 2022 (NDSU IPM).

At each field, the scout collected data both inside and outside fields. Outside each field, grass areas that bordered fields were swept for grasshoppers (**Figure 2**) and their nymphs (**Figure 3**).

Overall, after the 2021 drought and favorable overwintering conditions, wet spring weather likely allowed for some mortality of overwintering grasshopper eggs.

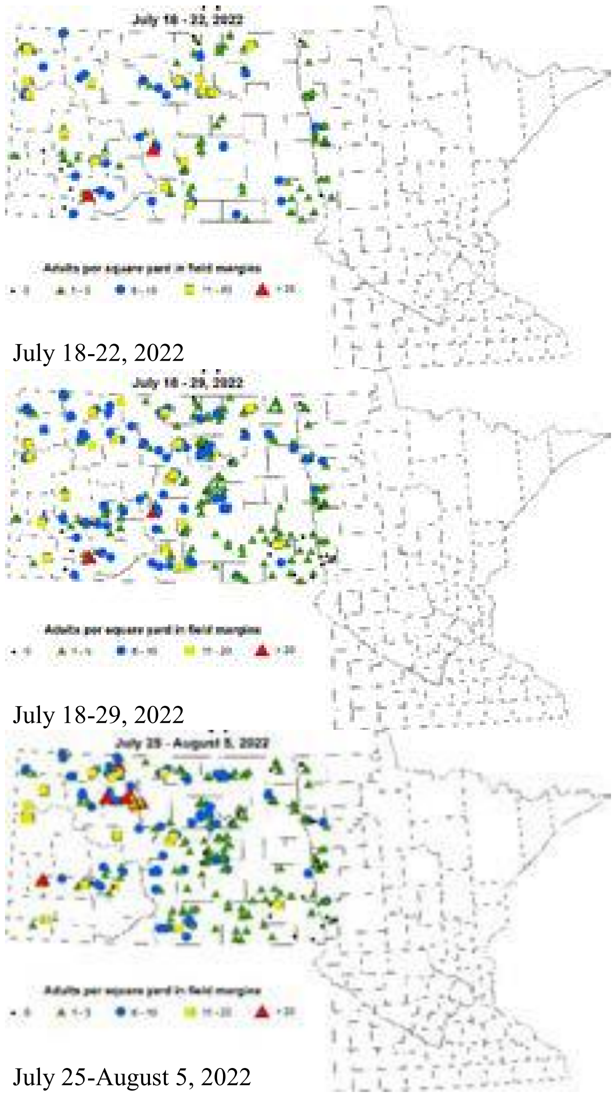
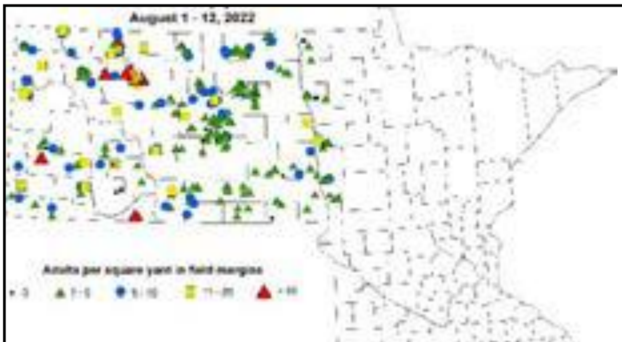


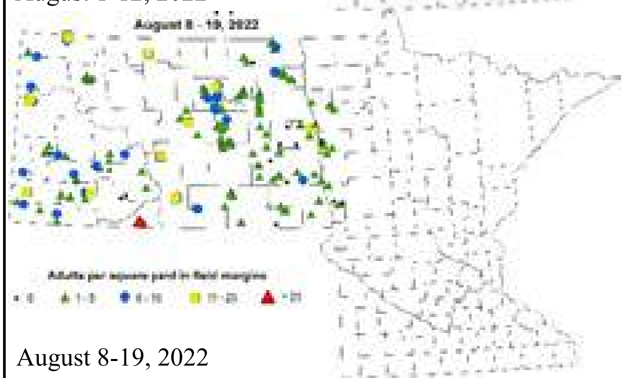
Fig 2. Grasshopper adults on the edge of scouted soybean fields, Jul 18-Aug 19, 2022; Map: NDSU IPM. Continued on next page.

For Additional Information:
Angie Peltier or Anthony Hanson

Funding Provided by:
Minnesota Soybean Research & Promotion Council

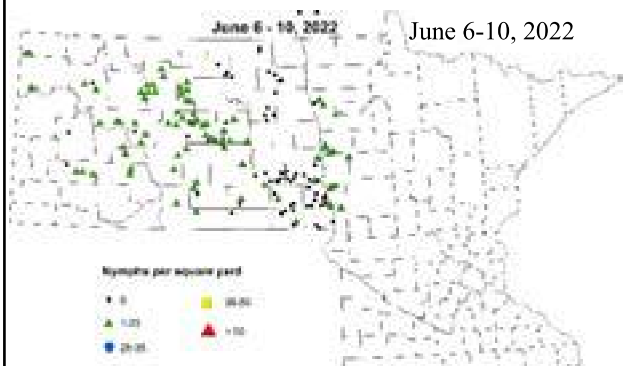


August 1-12, 2022

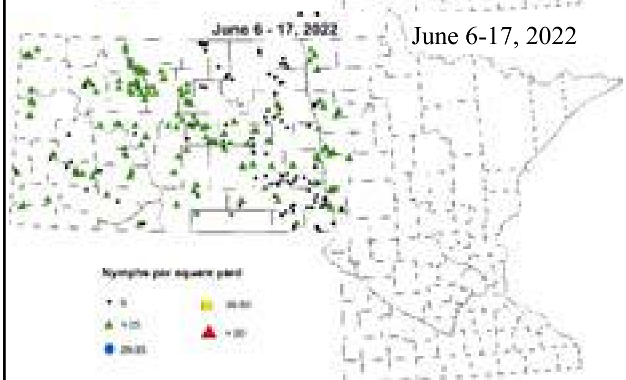


August 8-19, 2022

Fig 2. Grasshopper adults on the edge of scouted soybean fields, Jul 18-Aug 19, 2022; Map: NDSU IPM. Continued from previous page.

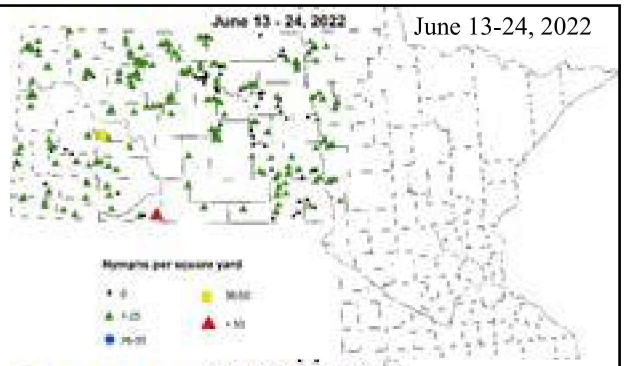


June 6-10, 2022

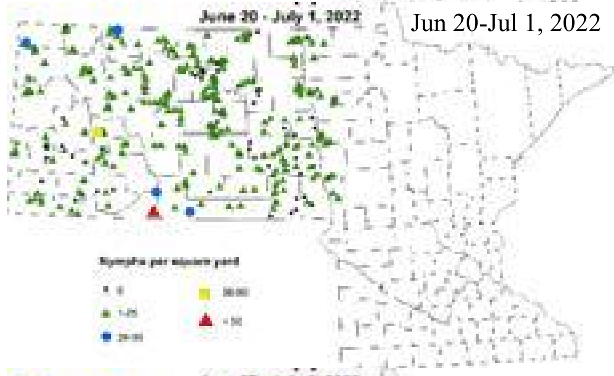


June 6-17, 2022

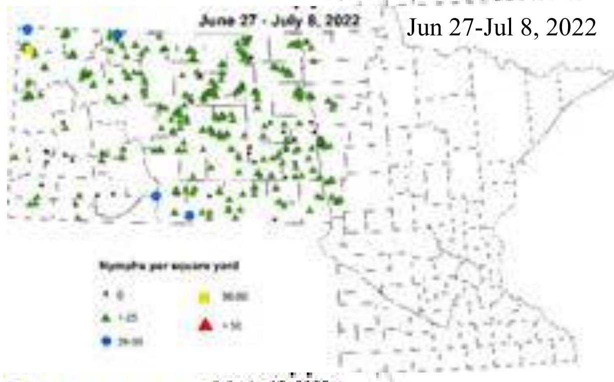
Fig 3. Continued in next column.



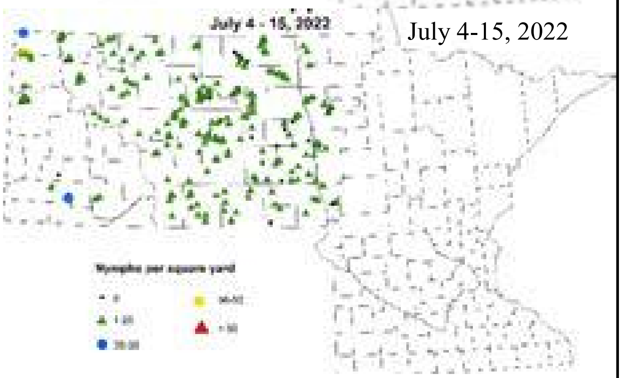
June 13-24, 2022



Jun 20-Jul 1, 2022



Jun 27-Jul 8, 2022



July 4-15, 2022

Figure 3. Grasshopper nymphs caught on edge of scouted fields from June 6-July 15, 2022 (Map: NDSU IPM). Continued from previous column and onto next page.

For Additional Information:
Angie Peltier or Anthony Hanson

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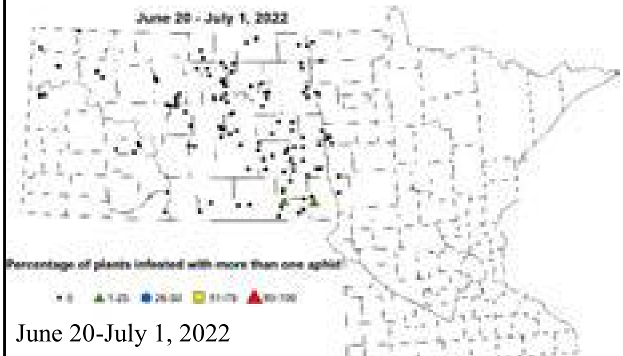
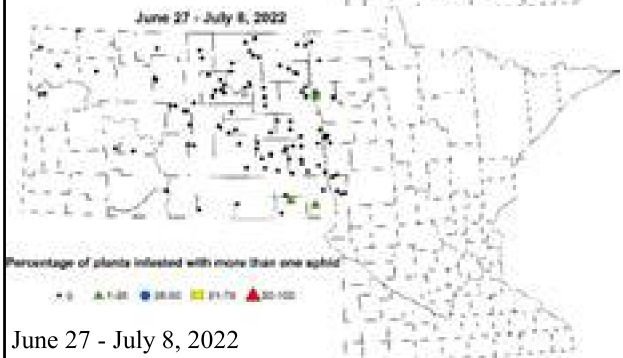
Continued on next page

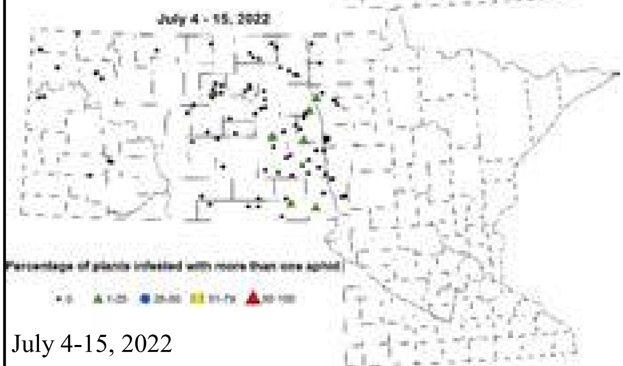
Although soybean aphid incidence (the percentage of plants within a field that were infested) continued to grow throughout the growing season (**Fig 4**), the population density, or average number of soybean aphids per plant, of these infestations remained well below the soybean aphid treatment threshold of 250 aphids per plant, averaging less than fewer than 200 aphids per plant at all but two locations (**Fig 5**).



June 20-July 1, 2022

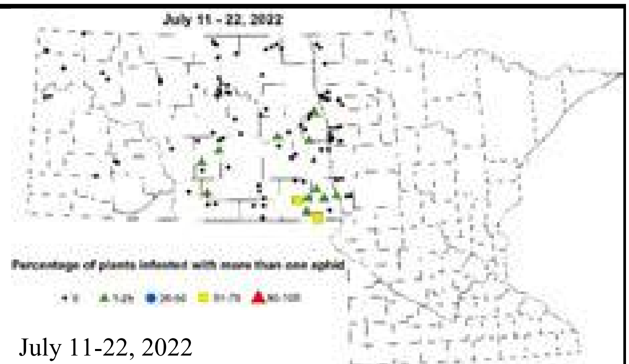


June 27 - July 8, 2022

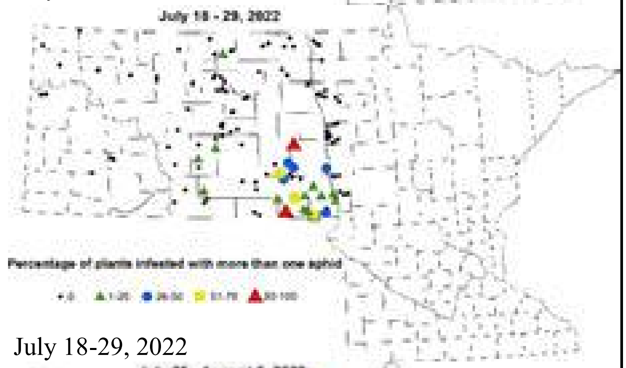


July 4-15, 2022

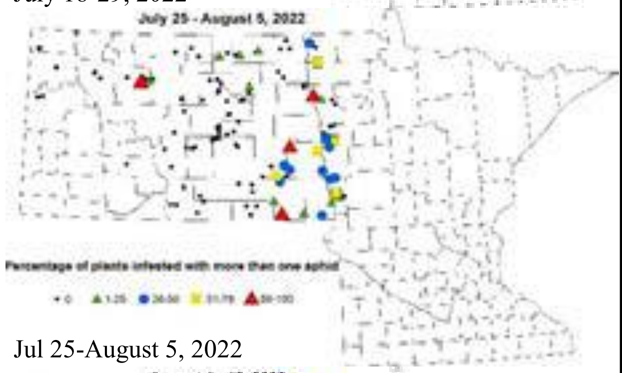
Figure 4. Percentage of surveyed soybean plants with at least one soybean aphid; Map: NDSU IPM. Continued in next column.



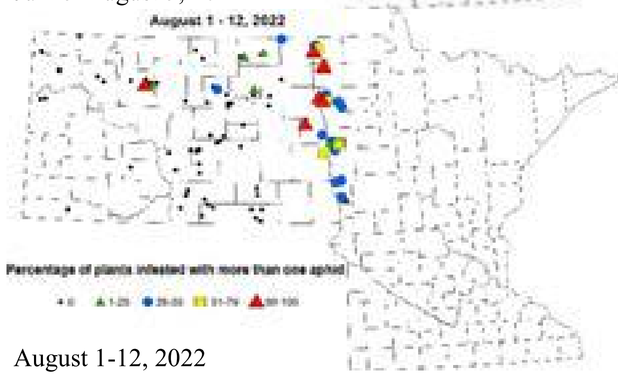
July 11-22, 2022



July 18-29, 2022



Jul 25-August 5, 2022



August 1-12, 2022

Figure 4. Percentage of surveyed soybean plants with at least one soybean aphid; Map: NDSU IPM. Continued from previous column and onto the next page.

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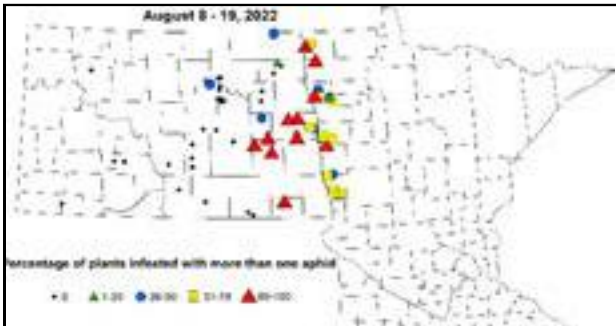
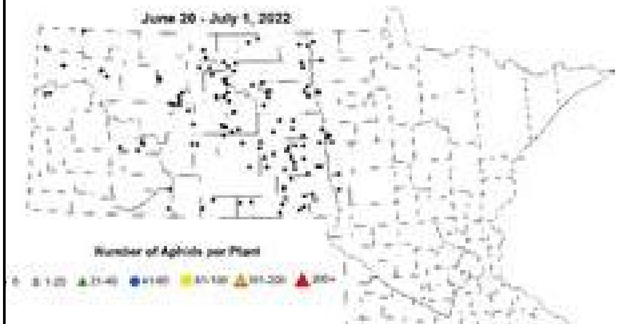
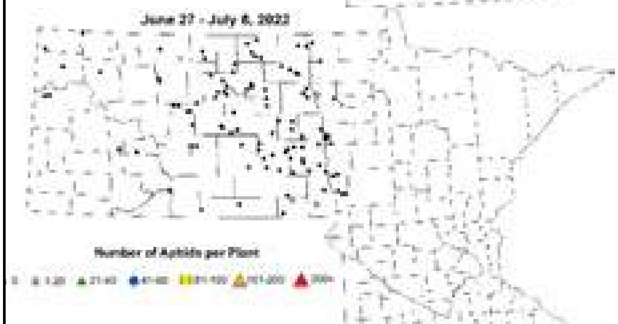


August 8-19, 2022

Figure 4. Percentage of surveyed soybean plants with at least one soybean aphid; Map: NDSU IPM. Continued from previous page.

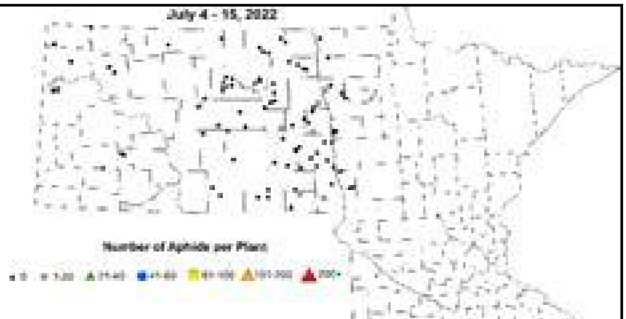


June 20-July 1, 2022

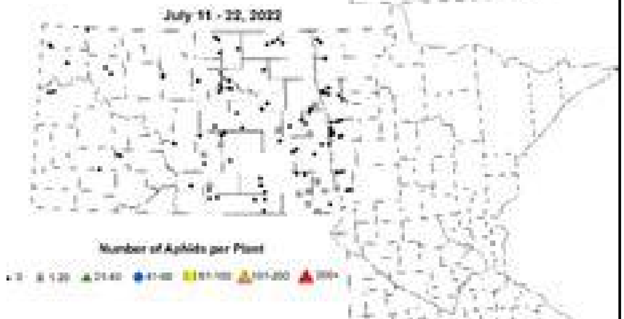


June 27-July 8, 2022

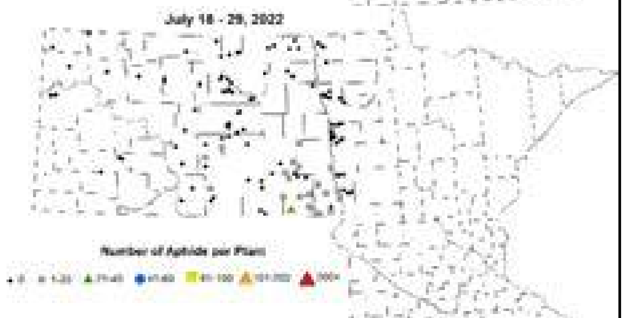
Figure 5. Soybean aphid severity (# of aphids per plant) over 2-week periods from June 20 to August 19, 2022; Map: NDSU IPM. Continued on next column.



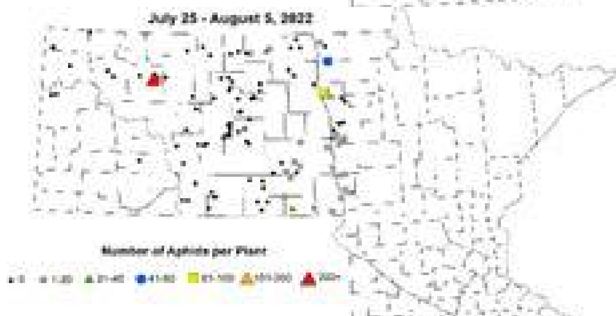
July 4-15, 2022



July 11-22, 2022



July 18-29, 2022



July 25-August 5, 2022

Figure 5. Soybean aphid severity (# of aphids per plant) over 2-week periods from June 20 to August 19, 2022; Map: NDSU IPM. Continued from previous column and onto next page.

For Additional Information:
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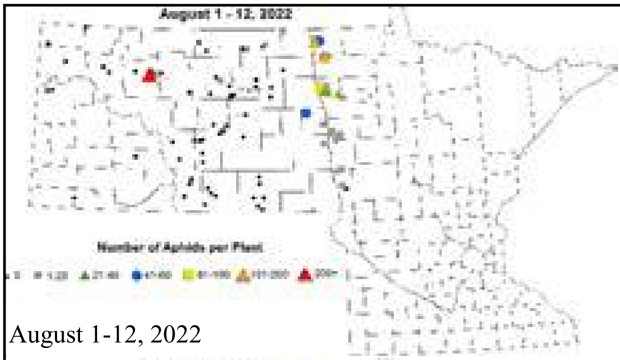
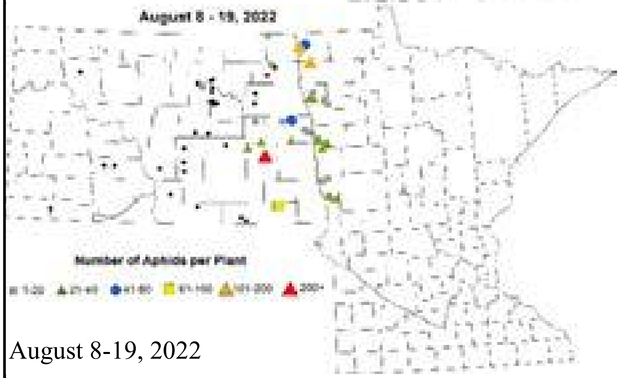


August 1-12, 2022

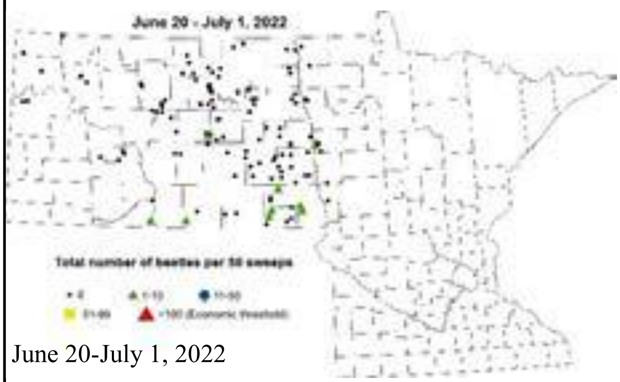


August 8-19, 2022

Figure 5. Soybean aphid severity (# of aphids per plant) over 2-week periods from June 20 to August 19, 2022; Map: NDSU IPM. Continued from previous page.

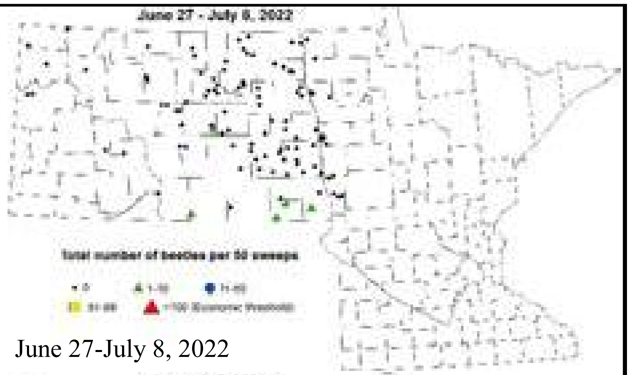
Aphid "mummies", or dead soybean aphids colonized by a parasitic wasp that is a natural enemy of the aphid were also scouted for, with only one scouted location with 5% of the plants colonized by wasps.

Few bean leaf beetles were captured with sweep nets (**Figure 6**) and average defoliation that they caused was 10% or less (**Figure 7**).

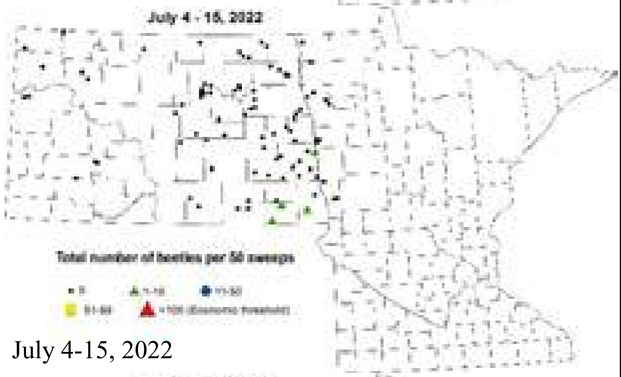


June 20-July 1, 2022

Figure 6. Number of bean leaf beetles per 50 sweeps over two-week periods from June 20 to August 19, 2022; Map: NDSU IPM. Continued.



June 27-July 8, 2022



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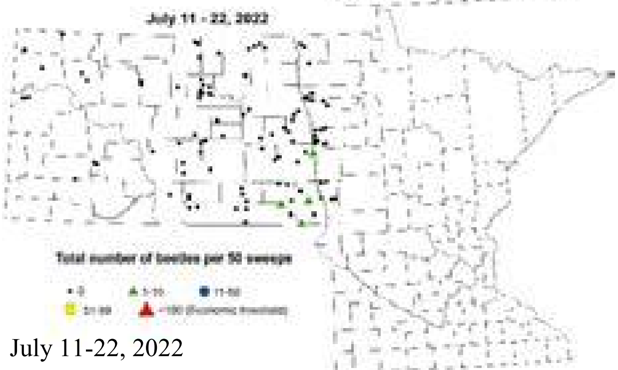

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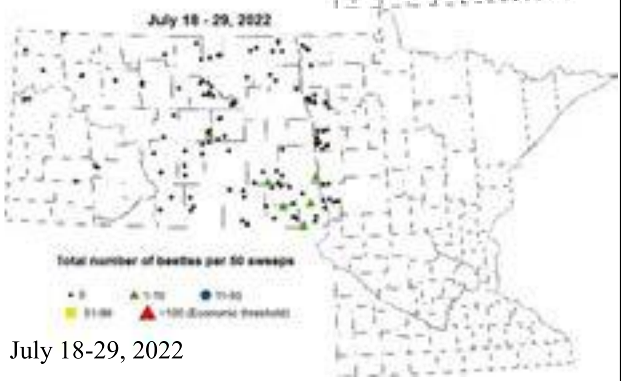

July 18-29, 2022

Figure 6. Number of bean leaf beetles per 50 sweeps over two-week periods from June 20 to August 19, 2022; Map: NDSU IPM. Continued from previous column and onto next page.

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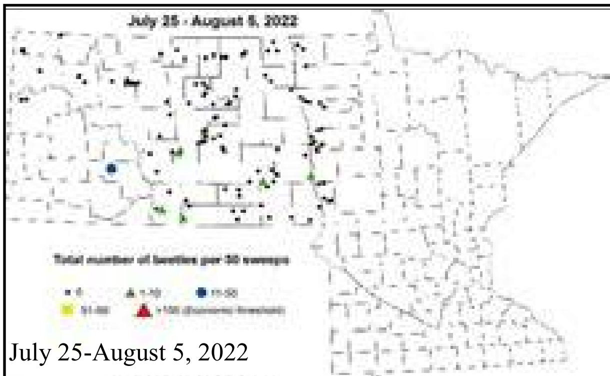
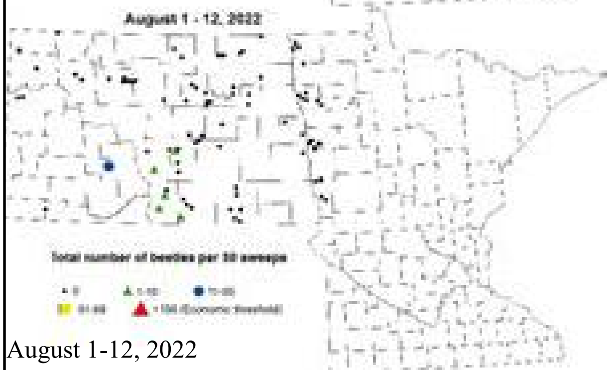
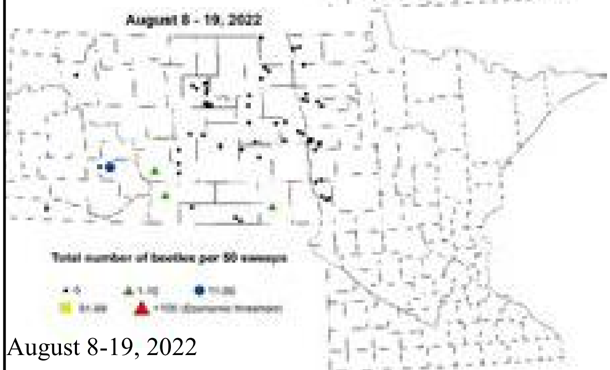


July 25-August 5, 2022

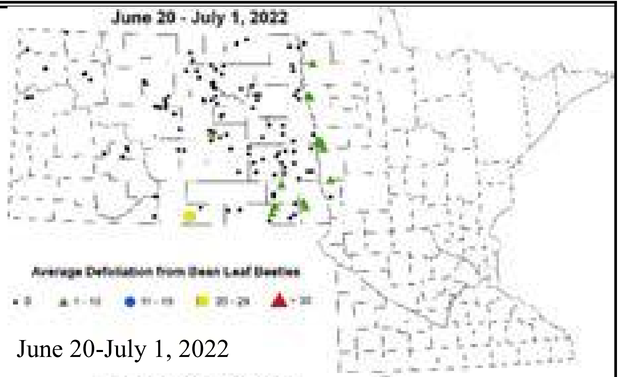


August 1-12, 2022

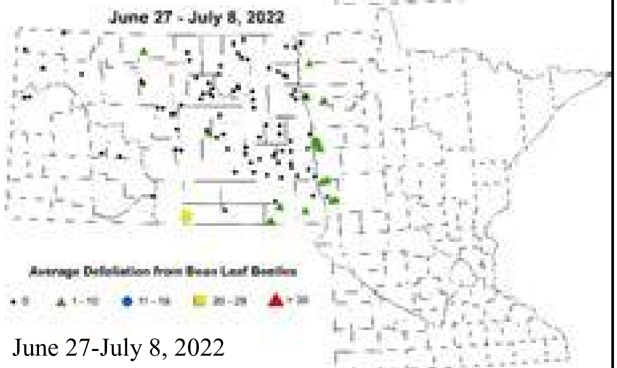


August 8-19, 2022

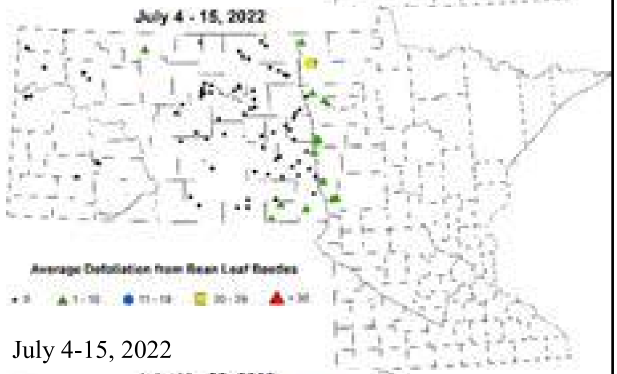
Figure 6. Number of bean leaf beetles per 50 sweeps over two-week periods from June 20 to August 19, 2022; Map: NDSU IPM. Continued from page.



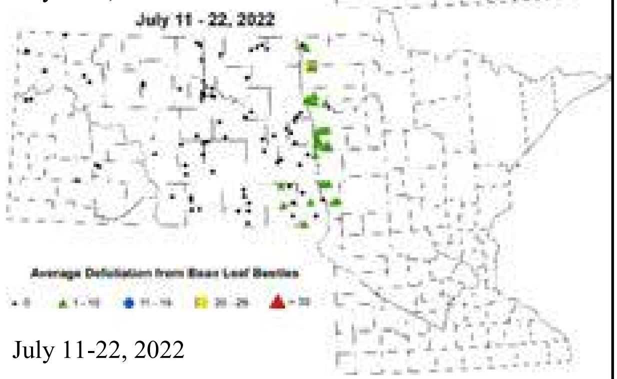
June 20-July 1, 2022



June 27-July 8, 2022



July 4-15, 2022



July 11-22, 2022

Figure 7. Average bean leaf beetle defoliation injury, June 20-August 19, 2022; Map: NDSU IPM. Continued on next page.

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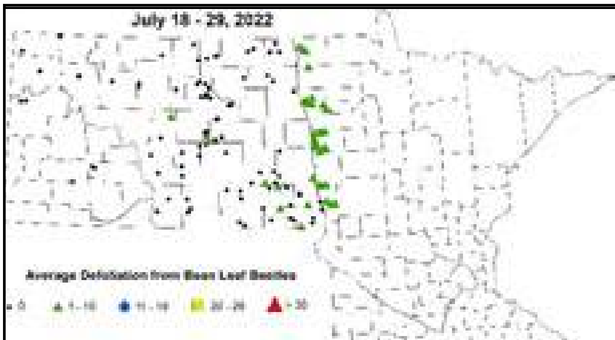
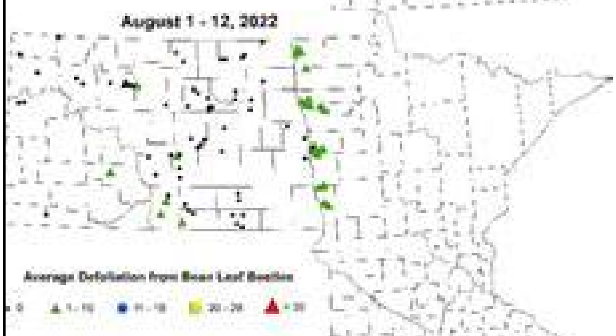
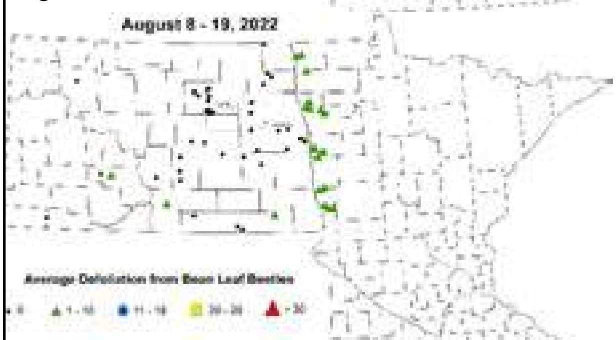


July 18-29, 2022

July 25-August 5, 2022



August 1-12, 2022



August 8-19, 2022

Figure 7. Average bean leaf beetle defoliation injury, June 20-August 19, 2022; Map NDSU IPM. Continued from previous page.

Unlike in 2021, when severe to exceptional drought conditions favoring spider mite infestations on plants growing along field borders and soybean plants within fields, spider mites were neither observed outside or within scouted fields in 2022.

While scouting for soybean gall midge larvae also took place in all surveyed fields for the first time in 2022, none were observed.

Preserving a.i.'s efficacy. Insecticides have been widely used in soybean production, often without consideration of treatment thresholds, as 'cheap and easy insurance' when added to the spray tank when making post-emergence herbicide or fungicide applications.

As scouted fields in NW MN did not reach treatment thresholds for commonly occurring pests like soybean aphids or two-spotted spider mites, unnecessary pesticide applications could have been avoided by most. Avoiding unnecessary applications helps to preserve a.i. efficacy. Each time that an insecticide or miticide is used, it selects those insects or mites that are resistant to that active ingredient(s) (a.i.) to survive and reproduce, killing those that are sensitive to the a.i. Over time this results in a population shift from one that is largely a.i.-sensitive to one that is largely a.i.-resistant.

Do your best to avoid unnecessary pesticide applications. Insecticide and fungicide applications can adversely affect biological control conferred by natural predators (like the parasitic wasps that colonize soybean aphids) or entomopathogenic fungi and may actually cause spider mite populations to flare up.

For Additional Information:
Angie Peltier or Anthony Hanson

Funding Provided by:
Minnesota Soybean Research & Promotion Council

Minnesota Small Grains Pest Survey

Dr. Anthony Hanson, Dr. Jochum Wiersma

Project Period: 01/01/2022 – 12/31/2022

Research Question/Objectives :
The goals of this pest survey are to produce timely alerts for small grain producers throughout the growing season so that sound economic control options can be implemented. We plan to integrate this survey with the ongoing efforts in North Dakota that are coordinated by NDSU's IPM Survey to improve efficiency and impact of this program across Minnesota and North Dakota. Specific project objectives include:

1. Survey small grain fields each week from mid-May through July in western and northwestern Minnesota small grain production areas monitoring for agronomic, insect and disease issues
2. Generate survey maps along with NDSU Extension cooperators regarding scout findings.
3. Provide timely alerts about pest and disease issues in small grains so that producers can implement sound economic control options.
4. Estimate the area in which wheat stem sawfly has established successfully as an economic pest in spring wheat in Minnesota

Results:
The 2022 small grain scouting program had 97 unique field visits during the 2022 small grain scouting season in approximately 23 fields. These fields were volunteered by producers in early spring and scouted throughout spring and early summer by one survey scout centered around the Moorhead area. Due to tight and extremely competitive hiring conditions this year, the remaining scout positions in Crookston and Morris were not able to be filled. Therefore, areas scouted focused on northwestern Minnesota ranging from Kittson County in the north to Wilkin County in the south. Scouting started in June 3 and continued until the crop had reached maturity in mid-July. Delayed planting from wet spring conditions also resulted in fewer fields available and volunteered this year.

Data was collected on severity and incidence of the major cereal diseases in Minnesota as well as some of the important insect pests. Data was submitted each week to the NDSU IPM team who generated distribution maps for the region (See Appendix). Archived distribution data can be found at: https://www.ag.ndsu.edu/ndipm for various crops. Postings were also made to the Minnesota Crop News Blog at https://blog-crop-news.extension.umn.edu/ for commentary on disease development. There was a total of 11 pest updates posted to the Minnesota Crop News Blog, with a total of over 2780 views, averaging nearly 250 views per post.

In general, 2022 was another quiet year for small grain diseases. Despite initial cool wet conditions, very few diseases were found throughout the growing season, largely due to lack of moisture in many parts of the state later in summer, which did not provide conditions conducive for many of the fungal diseases to develop. Tan spot was the only major disease found in some Minnesota fields at up to 50% incidence.

Cereal aphids were not found in the sampled areas this year. This may be due to the reduced sampling area and number of fields, though aphid reports from growers were also low this year. However, barley yellow dwarf virus, which is vectored by those aphids, was also not found in the survey this year. Grasshoppers appeared in the sweep net samples from early-June onward, though both adults and nymphs were at low populations throughout the year. Grasshopper populations were high last year going into last fall, so risk was originally high this spring. Cool wet weather this spring likely helped control and reduce grasshopper populations before they became a major risk. Wheat stem sawfly was not found in the survey, but two fields in Minnesota were found with stem maggot at 11-20% incidence. The Season Summary maps by disease or insect are provided as a reference in an appendix at the end of the report (Appendix 1)

Application/Use:
Results from this scouting project are used widely by farmers, crop consultants, and Extension educators throughout Minnesota. The in-season commentary published to the Minnesota crop news blog provides Minnesota farmers with real-time pest issues and recommendations to make informed pest management decisions.

Continued on next page →

These results were also used to give updates during summer webinars, such as Strategic Farming: Field Notes. These findings were also included at in-person events such as Farmfest where growers could ask about current pest issues during the year and the Institute for Ag. Professionals Field School in St. Paul wheat pest ID sections.

Materials and Methods:
Three scouts operating throughout western Minnesota scouted approximately 20-30 small grains fields per week during the small grain growing season. Scouts underwent training at the beginning of the season with the NDSU IPM scouts to learn how to identify and score pest incidence and severity and how to record the data collected. The MN survey was conducted according to the same protocol followed by the NDSU IPM survey so that the output could be merged and reflect a regional effort. The only difference from the North Dakota survey is fields in Minnesota are volunteered each spring to ensure we have permission to scout various fields in addition to variety trial locations. Scouts collected GPS data to aid the construction of distribution maps for each week of data collected for each disease/ insect pest. Fields were scouted by walking out past the headland in each field and walking a "w" pattern and taking observations of 10 plants at each point of the "w". Sweep nets were used to monitor the number of grasshoppers per four sweeps in field margins and ditches. Incidence and severity data were collected for Leaf rust, Tan Spot, Septoria spot blotch, and FHB. Incidence only data was collected for Bacterial leaf streak, Barley yellow dwarf, Wheat streak mosaic virus, Stem rust, Stripe rust, Powdery mildew and Loose smut. For FHB, scab index was calculated by combining the severity and incidence data. The weekly scouting data was combined and sent to the NDSU IPM team who then used this data to construct both weekly distribution maps, as well as end of season maps. Data was interpreted and distributed weekly as commentaries posted to the Minnesota Crop News blog.

Economic Benefit to a Typical 500 Acre Wheat Enterprise:
A follow-up survey to the users of the Minnesota Crop News blog and the disease risk assessment websites is necessary to fully assess whether the timely disease and pest updates and commentary altered producer decisions for their disease and pest management in 2022. Each update posted to the Minnesota Crop News Blog had an average of nearly 250 page visits, indicating a large potential impact with this scouting program as most Minnesota Crop News blog subscribers are farmers or crop consultants. Even small impacts on a typical wheat enterprise have the potential for large economic benefits, as informed pest management decisions can easily provide impacts of more than $10 per acre, with drastically greater impacts in some situations. Even at these conservative levels a 500 acre wheat enterprise could increase gross returns by $5,000 in a given year with timely alerts. This year, the lack of major pest issues in the surveys would reassure growers that risk was low for economic loss for pests, and that extra costs for pest management largely were not needed.

Related Research:
This project directly ties in with the North Dakota State University Integrated Pest Management scouting program in North Dakota as reflected by the regional scouting maps produced between the two programs. This project also ties in with the Wheat Stem Sawfly screening program in an effort to identify the geographic area affected by Wheat stem sawfly. This project also ties with the Minnesota Soybean Scouting project funded by the Minnesota Soybean Research and Promotion Council, as these programs complement each other, providing a full summer scouting experience for our crop scouts, who are able to scout small grains in the spring and early summer while shifting to soybeans mid-summer.

Recommended Future Research:
The PIs would like to continue the small grains pest survey across the state to continue monitoring pest levels in the state and to continue providing well-informed commentaries for Minnesota small grain producers into the future. The hope is to expand the scouting program to include three locations in the state again to obtain better coverage of fields in the western half of the state.

Publications :
Minnesota Crop News (https://blog-crop-news.extension.umn.edu/)

- Small Grains Disease Update 06/01/2022. 217 views.
- Small grains disease update 06/09/2022. 193 views.
- Small Grains Disease and Pest Update 06/15/2022. 163 views.
- Small Grains Disease and Pest Update 06/22/22. 278 views.
- Small Grains Disease and Pest Update 06/30/22. 181views.
- Small Grains Disease and Pest Update 07/06/22.

214 views.

- Small Grains Disease and Pest Update 07/12/22. 327 views.
- Small Grains Disease and Pest Update 07/20/22. 322 views.
- Small Grains Disease and Pest Update 08/10/22. 340 views.
- Small Grains (Harvest) Update. 545 views.

Strategic Farming: Field Notes webinar and podcast (https://strategicfarming.transistor.fm)

- May 19. "Field Notes discussed cool, wet spring and forecast's impact on crop and pest development". 332 views.
- June 21. "Strategic Farming: Field Notes session discusses early-season pest and weed management challenges". 200 views
- August 16. Strategic Farming: Field Notes. Late-summer forage small grains outlook". 207 views.

Cropping Issues in NW MN (https://blog-nwcrops.extension.umn.edu/)

- August 25. "NW MN IPM Survey Results". 54 page views.

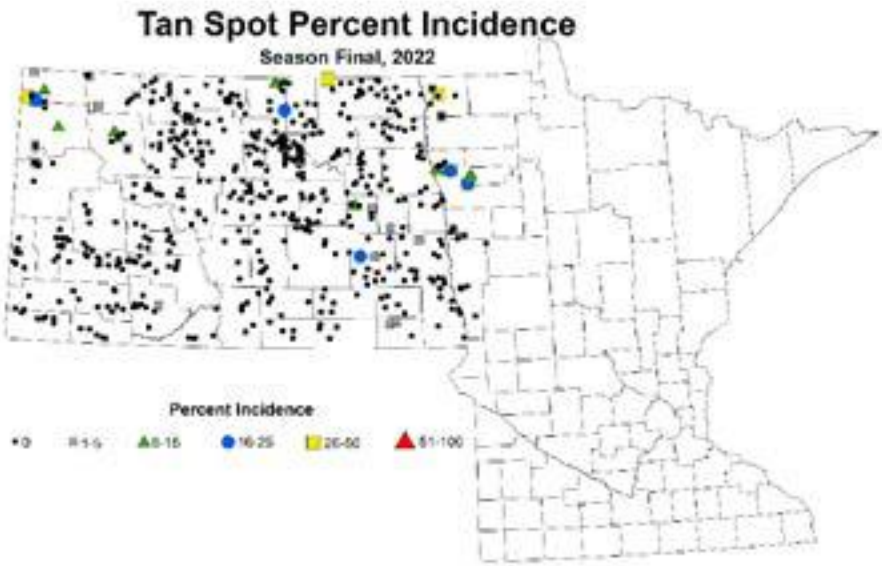
In-person programs
UMN Field School, UMN campus-area research farm, St. Paul, MN

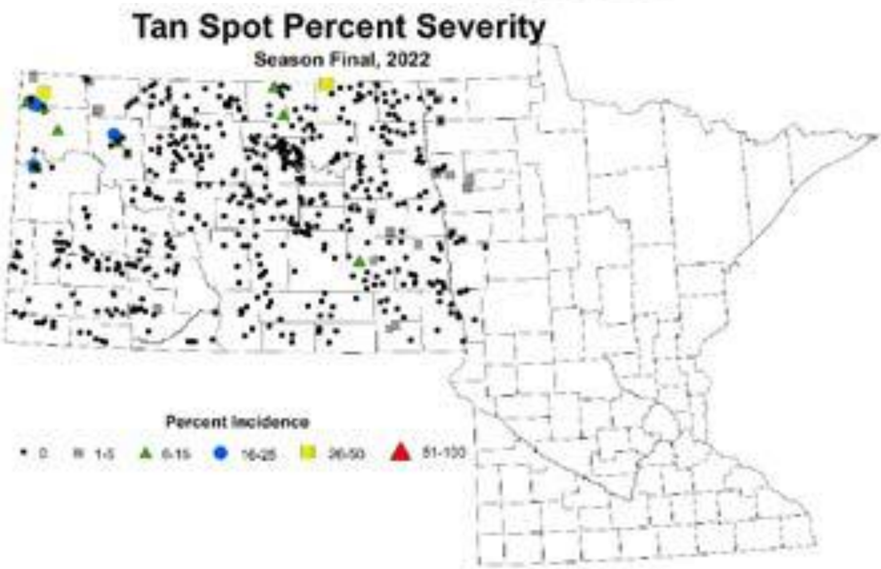
- July 20: Crop Pest Management sessions (2), Robert Koch and Anthony Hanson, ~30 participants
- July 21: Soybean Insect Scouting & Management sessions (2), Robert Koch & Anthony Hanson, ~ 30 participants.

Farmfest, Redwood Falls, MN

- August 3-4: UMN IPM Tools of the Trade booth.

Appendix I:





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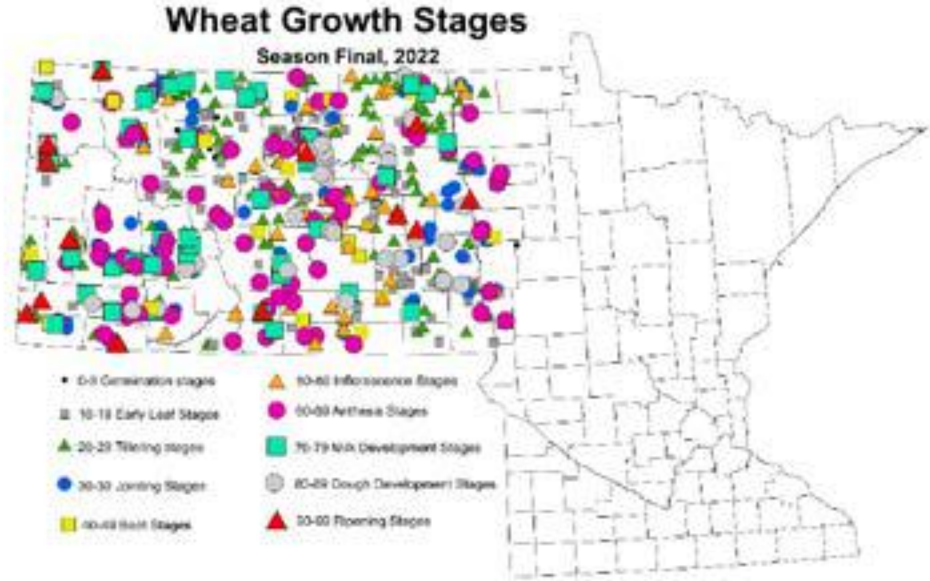
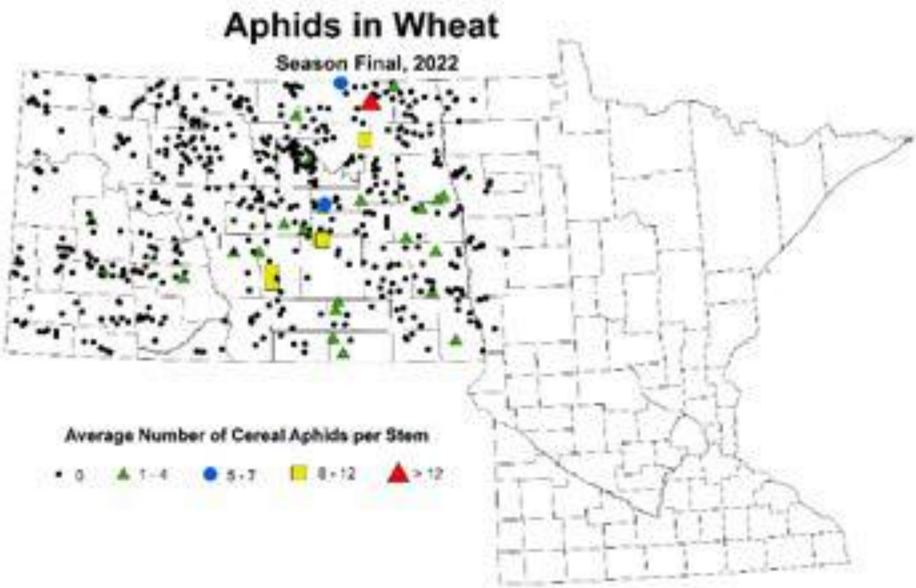
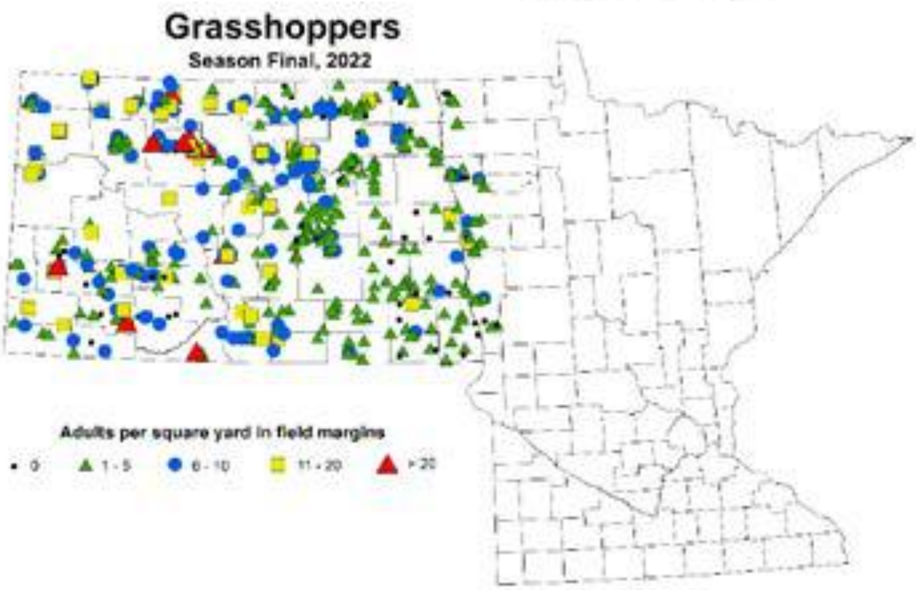
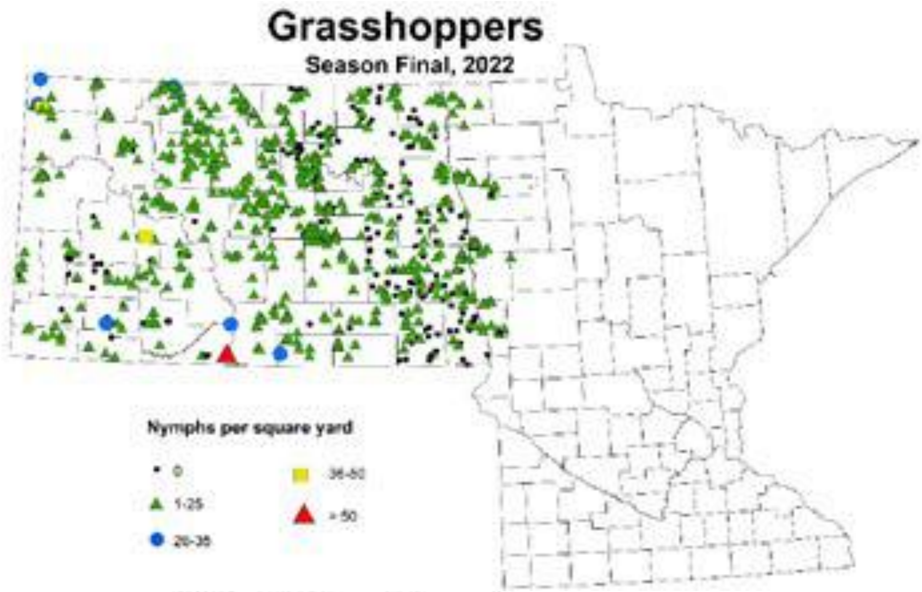
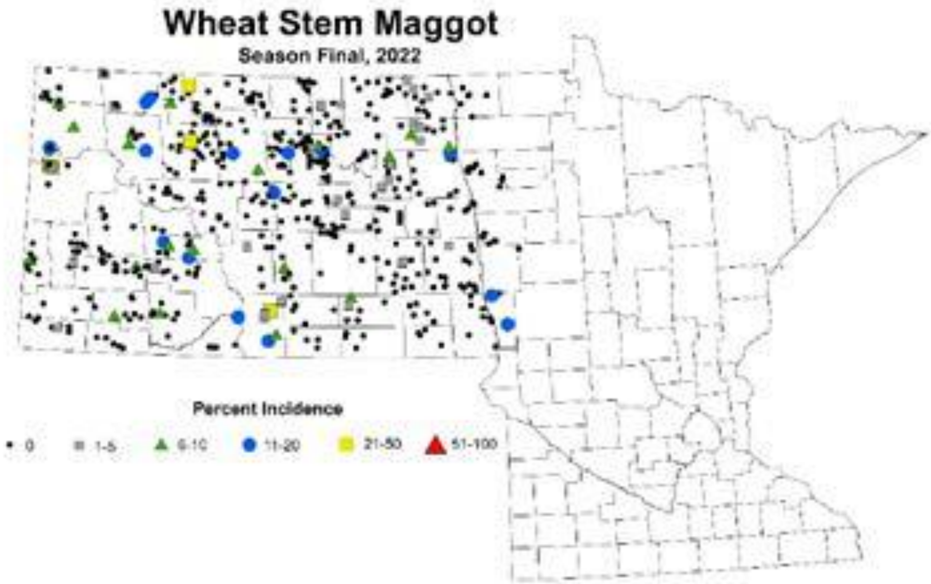
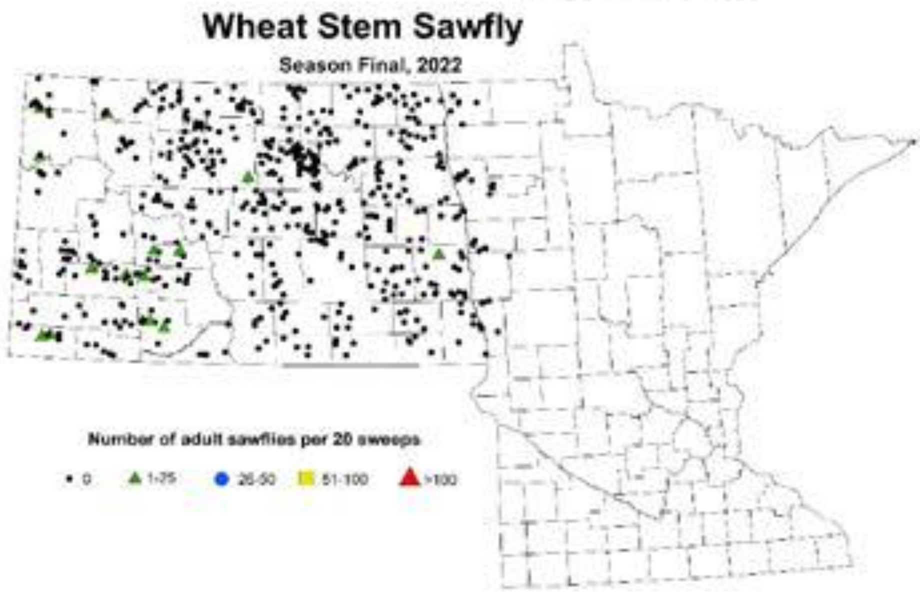

Wheat Growth Stages
Season Final, 2022

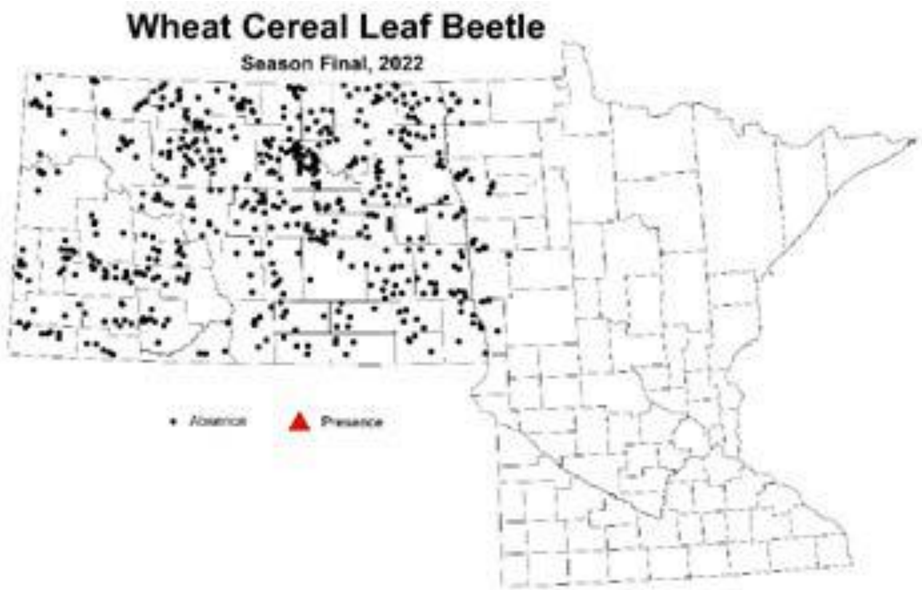

Aphids in Wheat
Season Final, 2022
Average Number of Cereal Aphids per Stem
0
1 - 4
5 - 7
8 - 12
> 12

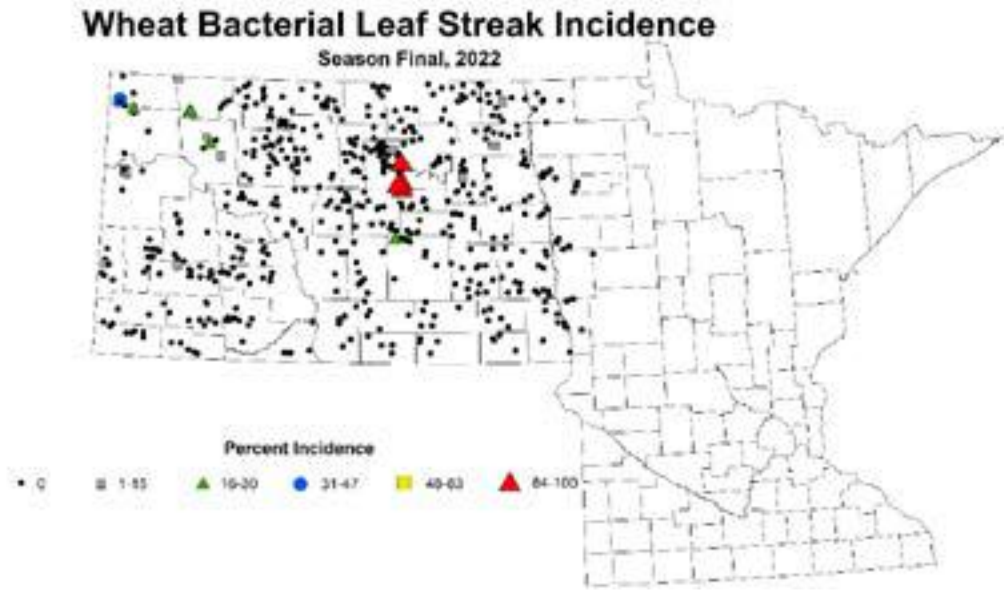

Grasshoppers
Season Final, 2022
Adults per square yard in field margins
0
1 - 5
6 - 10
11 - 20
> 20

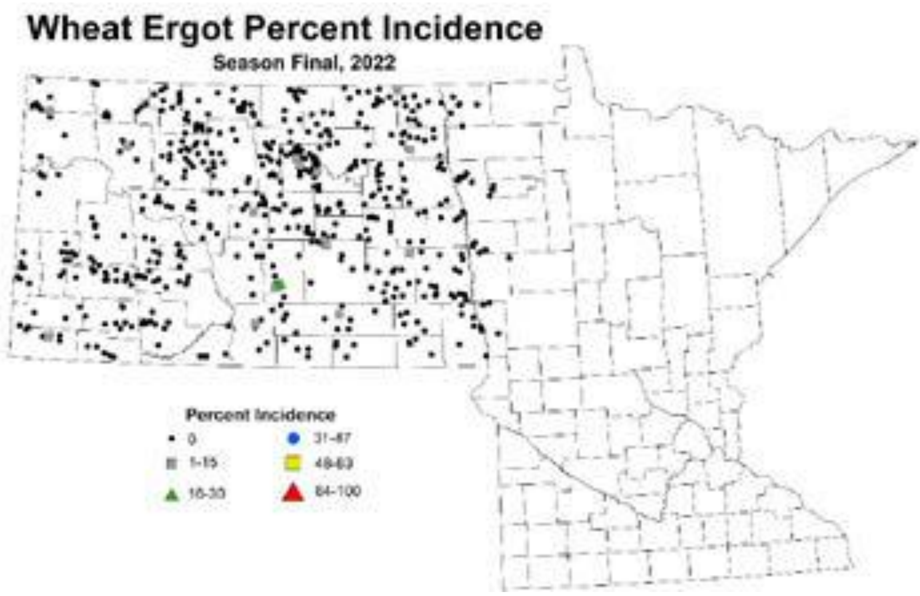

Grasshoppers
Season Final, 2022
Nymphs per square yard
0
1-25
26-35
36-50
> 50

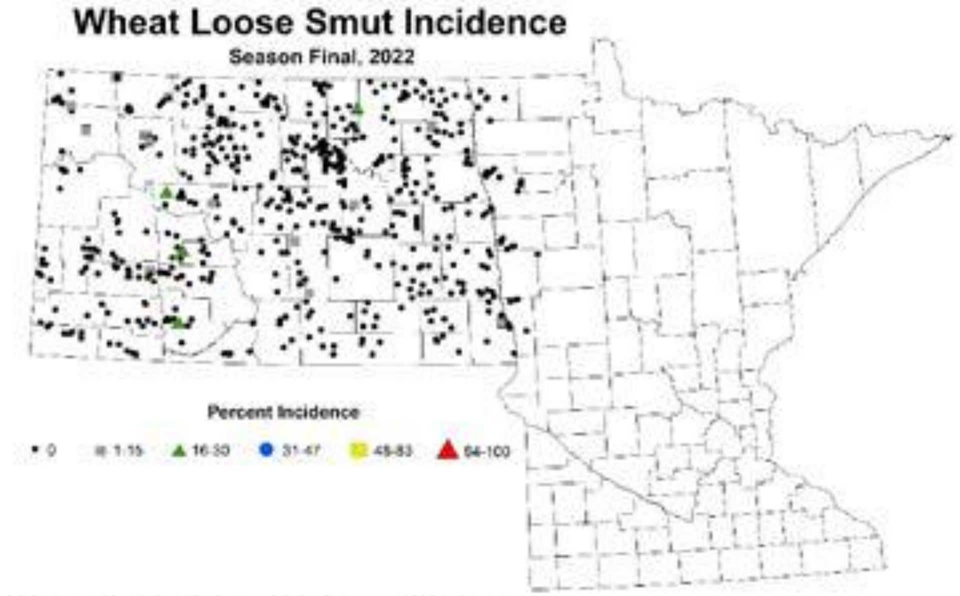

Wheat Stem Maggot
Season Final, 2022
Percent Incidence
0
1-5
6-10
11-20
21-50
51-100

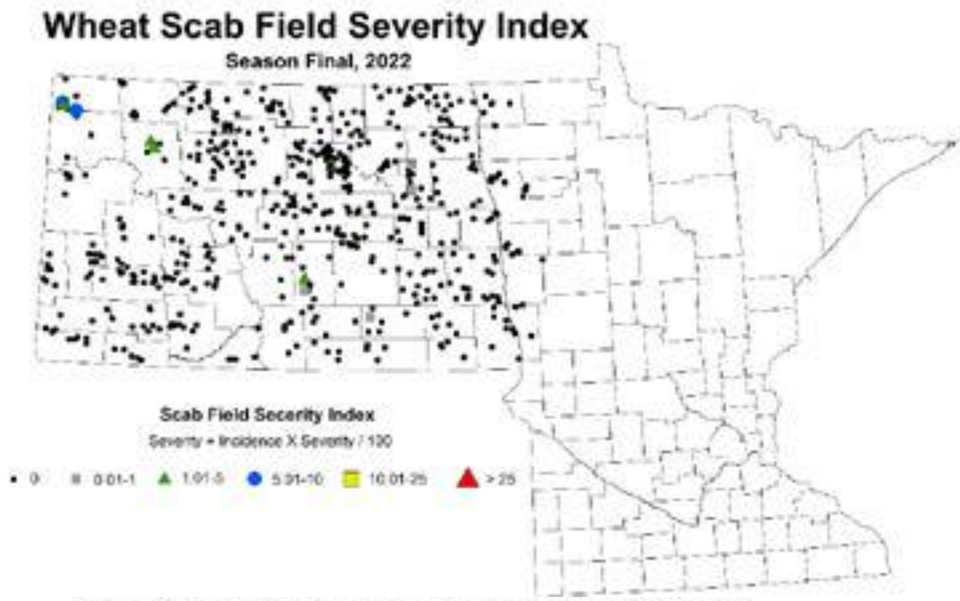

Wheat Stem Sawfly
Season Final, 2022
Number of adult sawflies per 20 sweeps
0
1-25
26-50
51-100
>100

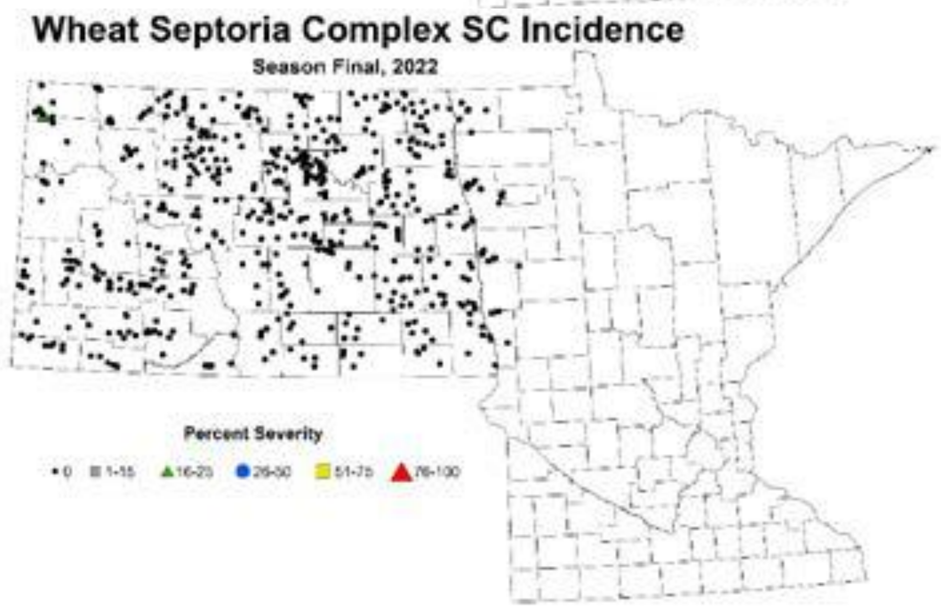

Wheat Cereal Leaf Beetle
Season Final, 2022
Absence
Presence


Wheat Bacterial Leaf Streak Incidence
Season Final, 2022
Percent Incidence
0
1-15
16-30
31-47
48-63
64-100


Wheat Ergot Percent Incidence
Season Final, 2022
Percent Incidence
0
1-15
16-30
31-47
48-63
64-100


Wheat Loose Smut Incidence
Season Final, 2022
Percent Incidence
0
1-15
16-30
31-47
48-63
64-100


Wheat Scab Field Severity Index
Season Final, 2022
Scab Field Severity Index
Severity = Incidence X Severity / 100
0
0.01-1
1.01-5
5.01-10
10.01-25
> 25


Wheat Septoria Complex SC Incidence
Season Final, 2022
Percent Severity
0
1-15
16-25
26-50
51-75
76-100

2022 Hard Red Spring Wheat Regional Quality Survey

Dr Shahidul Islam/Dr Richard Horsley

Project Period: 01/01/2022 to 12/31/2022

Research Question/Objectives:
Annual survey of hard red spring wheat grown in the Minnesota as part of North Great Plain states. The survey encompasses sample collection, analysis, and reporting important wheat quality attributes useful for marketing the crop. The range of environmental diversity, cultivars and agronomic practices results in a range of quality attributes and assessment of important marketing attributes of wheat entering into the commercial market channels.

Results:
A total of 117 samples of hard red spring wheats were collected from the state of Minnesota under two regional crop reporting areas (A and B). The number of samples collected was based on wheat production within each individual county. The greater the production the more samples were collected. In low producing counties a minimum of two samples were collected and in high producing counties a maximum of fifteen samples were collected. Every effort was made to obtain samples that accurately reflect condition of grain within an area that is available to the commercial market. The samples were collected under contract by the USDA-National Agricultural Statistics Service, located in Fargo, ND.

Table 1: list of the collected samples

County	Samples collected
Region A	
Kittson	15
Roseau	13
Marshall	13
Polk	15
Pennington	10
Red Lake	8
Norman	15
Mahnomen	4
Lake of the Woods	2
Region B	
Clay	8
Becker	4
Wilkin	7
Ottertail	3
Traverse	0
Grant	0

Approximately sixty percent of the HRS wheat samples obtained were graded by a federally licensed grain inspector. Additionally, these same samples were analyzed for protein content, falling number, test weight and thousand-kernel weight. Estimates of assay distributions within the wheat crop are made from these data. Samples representing each of the two hard red spring wheat crop reporting areas (CRA's) of Minnesota were prepared by combining equal portions of individual collected samples. Complete analyses were performed on those composite samples to assess quality. Assays include test weight, falling number, size distribution, protein, ash, 1000-kernel weight, grade, wet gluten, solvent retention capacity (SRC) etc. Milling yields were determined, along with flour ash and protein. The dough testing for the HRS wheat was the Farinograph, Alveograph and Extensograph. End-product performance model system is bread (100 g pup loaves). Bread criteria evaluated are baking absorption, bread loaf volume, crumb and crust color, symmetry, grain, and texture properties. Results of these analyses were reported on multiple tables in the published bulletin and presented in the following pages. Bulletins summarizing the HRS growing states findings were published for distribution primarily by the sponsoring agencies. Approximately 4,100 copies of report were printed. The data are also available electronically on the North Dakota Wheat Commission website.

In addition, wheat samples representing protein ranges of less than 13.5%, 13.5% to 14.5%, and greater than 14.5% protein (12% moisture basis) were prepared from the existing sample population. Complete wheat, flour, and bread baking analyses were performed on the protein-range samples. Reports summarizing the findings were submitted to U.S. Wheat Associates for incorporation into their international wheat marketing brochure.

Table 2: Wheat grading data

Crop Growing Area	Test Weight (lb/bu)	Test Weight (KG/HL)	Damaged Kernel (%)	Foreign Materials (%)	Shrunken/Broken kernel (%)	Total Defects (%)	Wheat of Contrast Classes (%)	Grade	Vitreous Kernel (%)
MN A	63.0	82.9	0.1	0.0	0.4	0.5	0.0	1 NS	61
MN B	62.4	82.1	0.1	0.0	0.6	0.7	0.0	1 NS	52
2022 Avg	0.0	1.4	0.0	0.0	0.0	0.0	0.0	1 NS	0
2021 Avg	62.8	82.5	0.0	0.0	0.4	0.4	0.0	1 DNS	83

Table 3: Kernel quality data

Crop Growing Area	Dockage (%)	Moisture (%)	1000 Kernel Weight (g)	Kernel Size Distribution medium (%)	Kernel Size Distribution large (%)	Protein Content (%) [Dry basis]	Protein Content (%) [12% moisture basis]	DON (ppm)	Wheat Ash (%)	Wheat Falling Number (sec)	Zeleny Sedimentation (cc)
MN A	0.4	12.8	34.4	34	64	15.5	13.7	0.0	1.45	397	62
MN B	0.3	13.0	29.9	56	41	15.8	13.9	0.0	1.56	386	63
2022 Avg	0.4	12.9	33.5	38	59	15.6	13.7	0.0	1.47	395	62
2021 Avg	0.3	12.4	33.9	49	49	16.8	14.8	0.0	1.43	406	67

Table 4: Flour quality data

Crop Growing Area	Extraction (%)	Flour Ash (%)	Flour Protein (%)	Starch Damage (%)	Wet gluten (%)	Gluten Index	Falling Number (sec)	Peak 65G FL	SRC: GPI	SRC: Water	SRC: 50% Sucrose	SRC: 5% Lactic Acid	SRC: 5% Sodium Carbonate
MN A	66.7	0.44	12.1	5.1	28.6	99	396	728	0.69	69	115	144	95
MN B	67.3	0.48	12.3	5.0	31.7	99	397	664	0.67	70	113	143	101
2022 Avg	66.8	0.44	12.2	5.1	29.3	99	396	715	0.68	69	115	144	96
2021 Avg	67.1	0.49	13.7	5.6	35.6	96	408	755	0.72	72	116	153	97

Table 5: Dough physical properties data (Farinograph)

Crop Growing Area	Absorption	Peak Time	Stability	MTI	Quality Number
MN A	61.8	6.8	15.5	19	168
MN B	60.6	7.3	13.9	23	153
2022 Avg	61.6	6.9	15.2	20	165
2021 Avg	61.9	7.4	21.2	15	260

Table 6: Dough physical properties data (Extensograph and Alveograph)

Crop Growing Area	Extensograph						Alveograph			
	Extensibility 45 min	Resistance 45 min	Area	Extensibility 135 min	Resistance 135 min	Area	P	L	P/L	W
MN A	15.6	581	114	15.0	734	147	100	122	0.82	433
MN B	16.0	607	126	13.9	867	156	88	134	0.66	404
2022 Avg	15.7	586	116	14.8	761	149	98	124	0.78	427
2021 Avg	17.7	607	132	13.7	1117	200	86	125	0.69	395

Table 7: Baking data

Crop Growing Area	Absorption	Dough Handling	Loaf Volume	Grain & Texture	Crumb Color	Crust Color	Symmetry
MN A	67.0	9.0	900	8.0	8.0	10.0	8.0
MN B	66.1	9.0	960	7.0	8.0	10.0	7.0
2022 Avg	66.8	9.0	912	7.8	8.0	10.0	7.8
2021 Avg	65.3	9.0	860	7.4	8.0	9.0	7.8

Continued on next page

Application/Use:
This project is one of the most effective ways of marketing Minnesota grown HRS wheat. It helps to improve and maintain HRS wheat sales in both domestic and overseas markets. Quality analysis results are published immediately in HRS Regional Quality Report and US Wheat Associates Crop Quality Report. Both of these reports are used as the prime tools for the marketing of US Wheat. In addition, the project principal investigator Dr Shahidul Islam presented the quality analysis results to a number of international trade teams and milling companies from all over the world who are the major importers of U.S. hard red spring wheat. Also, the representatives of U.S. Wheat Associates have been presenting the quality analysis results to national and international buyers.

Materials and Methods:
SAMPLE COLLECTION – Each sample contained approximately 2 to 3 pounds of wheat, stored in sealed, moisture-proof plastic bags.
MOISTURE – Official USDA procedure using Dickey-John Moisture Meter.
GRADE – Official United States Standards for Grain, as determined by a licensed grain inspector. North Dakota Grain Inspection Service, Fargo, ND, provided grades for composite wheat samples representing each crop reporting area.
VITREOUS KERNELS – Approximate percentage of kernels having vitreous endosperm.
DOCKAGE – Official USDA procedure. All matter other than wheat which can be removed readily from a test portion of the original sample by use of an approved device (Carter Dockage Tester). Dockage may also include underdeveloped, shriveled and small pieces 0f wheat kernels removed in properly separating the material other than wheat and which cannot be recovered by properly rescreening or recleaning.
TEST WEIGHT – American Association of Cereal Chemists International (AACCI) Method 55-10. Measured as pounds per bushel (lb/bu), kilograms per hectoliter (kg/hl) = (lbs/bu X 1.292) + 1.419. *Approved Methods of the AACCI Approved Methods (11th Edition), St. Paul, MN.
THOUSAND KERNEL WEIGHT – Based on 10 gram sample of cleaned wheat (free of foreign material and broken kernels) counted by electronic seed counter.
KERNEL SIZE DISTRIBUTION – Percentages of the size of kernels (large, medium, small) were determined using a wheat sizer equipped with the following sieve openings:

- top sieve—Tyler #7 with 2.92 mm opening;
- middle sieve—Tyler #9 with 2.24 mm opening; and
- bottom sieve—Tyler #12 with 1.65 mm opening.

PROTEIN – AACCI (NIR) Method: 39.10.01 expressed on dry basis and 12 percent moisture basis.
ASH – AACCI Method 08.01, expressed on a 14 percent moisture basis.
DON – Analysis was done on ground wheat using a gas chromatograph with an electron capture detector as described in J. Assoc. Official Anal. Chem 79,472 (1996)
FALLING NUMBER – AACCI Method 56.81.04; units of seconds (14 percent moisture basis).
SEDIMENTATION – AACCI Method 56.61.01, expressed in centimeters.
FLOUR EXTRACTION – Samples are cleaned and tempered according to AACCI 26-01.02. The milling laboratory is controlled at 68 percent relative humidity and 72°F to 74°F. Milling is performed on a Buhler laboratory mill (Type MLU-202). Straight grade flour (of all six flour streams) is blended and reported as "flour extraction."The blended flour is rebolted through an 84 SS sieve. All mill settings are optimized to achieve maximum laboratory mill flour extraction with standardized ash content.
ASH – AACCI Method 08.01, expressed on a 14 percent moisture basis.
PROTEIN – AACCI Method 39.10.01 (NIR Method), expressed on a 14 percent moisture basis.
WET GLUTEN – AACCI Method 38.12.02, expressed on a 14 percent moisture basis determined with the glutomatic instrument.
GLUTEN INDEX – AACCI Method 38.12.02, determined with the glutomatic instrument as an indication of gluten strength.
FLOUR FALLING NUMBER – AACCI Method 56.81.03, units of seconds. Determination is performed on 7.0 g of Buhler milled flour (14 percent moisture basis).
AMYLOGRAM – (65 g) AACCI Method 22.10.01, modified as follows: 65 g of flour (14 percent moisture basis) are slurried in 450 ml distilled water, paddle stirrers are used with the Brabender Amylograph. Peak viscosity reported in Brabender units (B.U.), on a 14 percent moisture basis.
STARCH DAMAGE – AACCI Method 76.31.01. Amperometric method using SDmatic.
SOLVENT RETENTION CAPACITY (SRC) – AACCI 56-11.02, expressed on a 14 percent moisture basis. SRC is used to predict commercial baking performance. Flour is shaken with excess of four types of solvent, to determine the amount of solvent held by the flour. The four solvents used relate to the functionality to flour components as follows: Water – Water absorption; Sucrose – Non-starch polysaccharides; Lactic Acid – Glutenins; Sodium Carbonate – Damaged Starch; Gluten Performance Index (GPI) – is a ratio of the

Figure 1: Bread volume analysis of Minnesota A and B (top left two) crop growing areas in comparison with other 16 red spring wheat crop growing areas of hard of U.S.

solvents and used as an overall performance of flour glutenins especially in relation to bread wheat flour.

PHYSICAL DOUGH PROPERTIES FARINOGRAM – AACCI Method 54-21.02; constant flour weight method, small (50 g) mixing bowl. (Flour weight 14 percent moisture basis). Farionograph-E.

ABSORPTION – Amount of water required to center curve peak on the 500 Brabender unit line, expressed on 14 percent moisture basis.

PEAK TIME – The interval, to the nearest 0.5 min, from the first addition of water to the maximum consistency immediately prior to the first indication of weakening. Also known as dough development time.

STABILITY – The time interval, to the nearest 0.5 min, between the point where the top of the curve that first intersects the 500-BU line and the point where the top of the curve departs the 500-BU line.

MIXING TOLERANCE INDEX – The difference, in Brabender units, from the top of the curve at the peak to the top of the curve measured five minutes after the peak.

QUALITY NUMBER – AACCI Method 115. The length, expressed in mm, along the time axis, between the point of water addition and the point where the height in the center of the curve decreased by 30 BU compared to the height of the center of the curve at development time. Stronger flours have a higher quality number.

EXTENSOGRAM – AACCI Method 54-10.01; modified as follows: (a) 100 grams of flour (14 percent moisture basis), 2.0 percent sodium chloride (U.S.P.) and water (equal to farinograph absorption minus 2 percent) are mixed to optimum development in a National pin dough mixer; (b) doughs are scaled to 150 grams, rounded, moulded, placed in extensigram holders, and rested for 45 minutes and 135 minutes, respectively, at 30°C and 78 percent relative humidity. The dough is then stretched as described in the procedure referenced above. For conversion purposes, 500 grams equals 400 B.U.

EXTENSIBILITY – Total length of the curve at the base line in centimeters.

RESISTANCE – Maximum curve height, reported in Brabender units (B.U.).

AREA – The area under the curve is measured and reported in square centimeters.

ALVEOGRAPH – AACCI Method 54.30.02. Alveolab is used to measure dough extensibility and resistance to extension.

"P" – Maximal overpressure; related to dough's resistance to deformation.

"L" – Dough extensibility.

"W" – The "work" associated with dough deformation.

BAKING PROCEDURE – AACCI Method 10-09.01, modified as follows: (a) fungal amylase (SKB 15) replacing malt dry powder, (b) Instant dry yeast (1 percent) in lieu of compressed yeast, (c) 5 to 10 ppm

Continued on next page

ammonium phosphate, where added oxidants are required, (d) 2 percent shortening added. Doughs are mechanically punched using 6-inch rolls, and mechanically moulded using a National Laboratory Test moulder. Baking is accomplished in “Shogren-type” pans.

BAKING ABSORPTION – Water required for optimum dough baking performance, expressed as a percent of flour weight on a 14 percent moisturebasis.

DOUGH CHARACTER – Handling conversion assessed at panning on a scale of 1 to 10 with higher scores preferred.

LOAF VOLUME – Rapeseed displacement measurement made 30 minutes after bread is removed from the oven.

CRUMB GRAIN AND TEXTURE –Visual comparison to standard using a constant illumination source. Scale of 1 to 10, the higher scores preferred.

CRUMB COLOR – Visual comparison with a standard using a constant illumination source on a scale of 1 to 10, the higher scores preferred.

CRUST COLOR –Visual comparison with a standard using a constant illumination source on a scale of 1 to 10, the higher scores preferred.

SYMMETRY –Visual comparison with a standard using a constant illumination source on a scale of 1 to 10, the higher scores preferred.

Economic Benefit to a Typical 500 Acre Wheat Enterprise:

This project successfully contributed towards market development of Hard Red Spring (HRS) wheat grown in Minnesota. Wheat quality is recognized as the set of attributes and characteristics contributing to the end-product quality. Meeting the requirements of food manufactures in the production of marketable end-products is crucial for the sustainability of HRS wheat market. Each of the Millers and bakers has their own perceptions and needs which varies significantly between the international export markets based on the local consumers demand. Accordingly, U. S. millers and bakers have different requirements compared to their international counterparts. On the other hand, growers define quality as the set of traits that allow maximum economic return. Thus, quality has a multiplicity of meanings, dependent upon the market situation. It is the end user who ultimately establishes value associated with a given standard of quality.

This project utilizes the latest quality testing approaches to evaluate wheat quality for various end-use applications in both domestic and international markets.

Related Research:

The North Dakota State University Department of Plant Sciences has been conducting annual surveys of North Dakota grown hard red spring (HRS) wheats since the early 1960’s. Surveys encompassed collection, analysis, and reporting important wheat quality attributes useful for marketing the crop. In recognition that other Northern Great Plains states produce approximately 40 percent of the HRS grown in the region, the 1980 and successive surveys have included the four northern plains states that produce 90% of the HRS wheats grown in the U.S. More recently HRS grown in the three states of Pacific North West (PNW) has been included in the survey, covering approximately 95% of total U.S. production. The range of environmental diversity, cultivars, and agronomic practices results in a range of quality attributes. Thus, expanding the survey to encompass the entire Northern Great Plains and PNW growing regions allows assessment of important marketing attributes of HRS wheat entering into the commercial market channels.

Recommended Future Research:

Wheat quality analysis of every year’s production is strongly recommended to be continued as one of the most effective ways of marketing Minnesota grown HRS wheat.

Publications:

- 2022 Regional Quality Report, U.S. HARD RED SPRING WHEAT (https://ndwheat.com/uploads/7/22hrs.pdf).
- US Wheat Associates 2022 Crop Quality Report, HARD RED SPRING (https://www.uswheat.org/wp-content/uploads/2022-USW-Crop-Quality-Report-English.pdf).

Continued provision of rapid end-use quality characterization services to the University of Minnesota Wheat Breeding Program

Dr. George Amponsah Annor
Department of Food Science and Nutrition
University of Minnesota
1334 Eckles Avenue
Saint Paul, MN, 55108

Dr. James Anderson
Department of Agronomy and Plant Genetics
University of Minnesota

Project Period: January – December 2022

Research Question/Objectives:
How does breeding activities by the University of Minnesota Breeding Program affect end-use Quality of Wheat?

Results:
During this reporting period we analyzed about 500 wheat samples sent to us by the University of Minnesota Breeding program. These samples are remnants from New Zealand. These samples were analyzed for their protein aggregation kinetics using the Glutopeak tester (GPT). Based on the peak maximum time, torque maximum, torque before maximum, torque after maximum, startup energy, plateau energy and aggregation energy of the samples generated from the GTP, the water absorption of the samples were calculated. The calculations were done using regression equations developed earlier with funding from the MWRPC. The calculated water absorption of the samples analyzed are shown in Fig 1. The water absorption of the samples ranged from 42% for 18X155 variety to 71% for 17x239b-34, 18X228 MAS and 18X215 varieties. Linkert that was used a check sample had a predicted water absorption of 67%. The mean water absorption of the 500 samples analyzed was 58%. The ability to calculate these water absorptions using the GPT is very important in screening large amounts of samples at a very early stage of the breeding process.

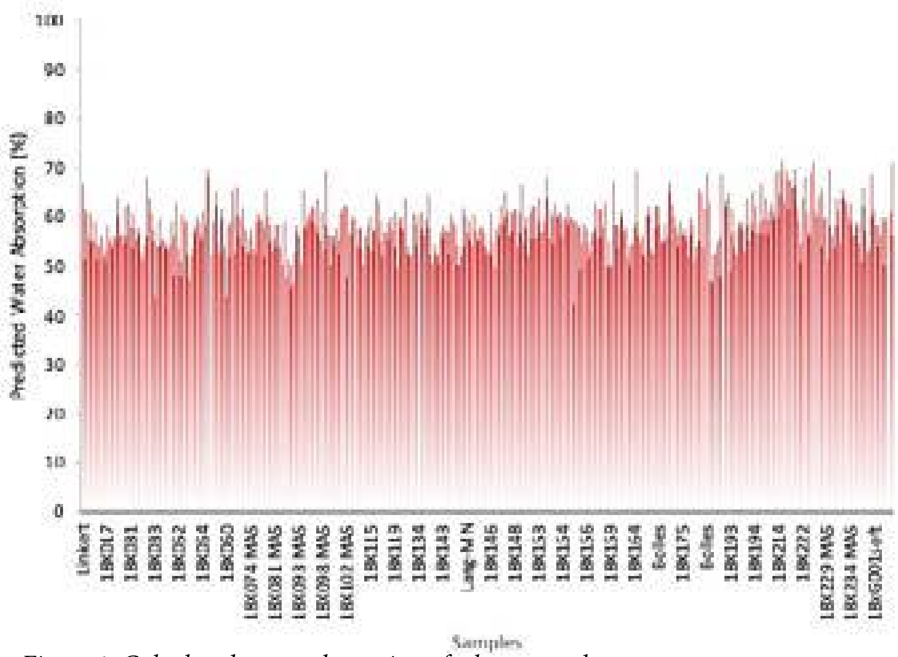


Figure 1: Calculated water absorption of wheat samples

Application/Use:
These calculated water absorptions, along with grain protein and test weight data are the only end-use quality data the breeding program will have to help decide which of these entries will be advanced for yield trials in 2022.

Materials and Methods:
500 wheat samples (2022 PY remnant (from NZ) were milled into flour and their protein aggregation kinetics determined using the Brabender Gluten Peak tester. The samples also included some checks as well.

Economic Benefit to a Typical 500 Acre Wheat Enterprise:
Results from this study enables the University of Minnesota Wheat breeding program to incorporate selection for good end-use quality earlier in the breeding efforts, thus avoiding the continued testing poor quality lines. The results of this research will be used to develop models that can be used to select for varieties with end-use quality parameters that are valued by our hard-red spring wheat customers. Such varieties will help to maintain the price premium of hard red spring wheat.

A novel high-throughput phenotyping pipeline to deliver more productive and stress resilient Minnesota wheat varieties

Walid Sadok, Daniel M Monnens, James A Anderson

Project Period: January 1, 2022 – December 31, 2022

Research Question/Objectives:
By capturing light, nitrogen and other nutrient resources from the roots, wheat canopies are the engine that fuels reproductive growth and therefore grain yields. While a highly productive and healthy canopy is a very desirable trait for a breeder, a challenge is that such canopies are nearly impossible to detect with the naked eye, which is not equipped to detect certain wavelengths that varieties emit when they are under-performing or stressed. For a breeding program, this challenge has to be addressed to enable rapid screening of hundreds if not thousands of breeding lines. To address this problem, we are developing a drone-based remote-sensing technology that is based on thermal imaging which is being tested to support the U of M wheat breeding program. This method differentiates between productive and underperforming canopies based on their thermal 'signatures'.

While there are existing drone-based approaches to monitor crops, our method is unique as it relies on advanced thermal imaging technology coupled with energy balance modeling, and informed by physiology-based ground truthing techniques. This combination of physiology-based techniques and remote-sensing methods ensures that differences in thermal images among genotypes actually captures differences in cultivar physiology rather than differences due to weather changes. This distinction is critical to any breeding program, because traits that are 'masked' by the environment will tend to have low heritability and are more difficult to genetically improve.

The main objective of our research was to deploy, test and validate our technology on a large population of 468 breeding lines (plus 5 checks) that are part of the U of M wheat Preliminary Yield Trials (PYT). In the first year, we have successfully deployed this technology and were able to use it to identify superior breeding lines that exhibited better yields under the droughty conditions of the 2021 summer. Our specific goals for this second year were to i) finalize our image processing pipeline and ii) replicate the field-based experiment in a second year.

Results:
Yield results from this year's PYTs are plotted in Figure 1. The preliminary results indicate that there is a large variability in yields, with 45% of breeding lines matching or out-yielding the best performing check. In this trial, the best performing breeding line out-performed the best check by nearly 24 bu/a, a performance higher than last year's, where the best breeding line out-yielded the best check by 16 bu/a.

The completed image analysis of last year's yield trial conducted on all breeding lines revealed a statistically significant and negative association between canopy warming and yield. That is, breeding lines with cooler canopies -as exemplified on Figure 2- tended to out-yield those with warmer ones. While needing confirmation based on this year's trial, this promising result shows that selecting for genotypes with cooler canopies is a promising breeding target.

Application/Use:
This research aims to develop a remote-sensing technology that enables rapid screening of breeding lines for canopy temperature, a trait directly related to yield performance. This technology is expected to support the U of M breeding program by making it possible for the breeder to more rapidly screen a larger number of breeding lines and identify promising ones at lower costs. Additionally, this technology could work in farmers' fields, potentially enabling them to monitor in real time the health status of their crop.

Materials and Methods:
The experimental design was an augmented incomplete block design with 5 checks in each block (14 blocks). A total of 468 genotypes plus 5 checks were planted in (4.5 ft x 8 ft) yield plots at the U of M St Paul campus on 05/05 and harvested on 08/04 and 08/05. After planting, aerial thermal images were collected over 14 flights 1-2 times per week from [06/01] (tillering) to [08/01] (physiological maturity) with a thermal camera (Vue Pro R 640) mounted on an unmanned aerial system (UAS; Inspire 2, DJI) using a specialized gimbal (VuIR Tab HD gimbal).

Flights always took place on sunny days around solar noon, i.e., between 13:00 and 13:30 hours. Along with the thermal images, RGB (Red-Green-Blue) images were collected using the drone RGB camera and gimbal (Zenmuse X5S, DJI). These RGB images were needed to align with the thermal images to differentiate soil from crop temperature and estimate the change in canopy cover over time, and to obtain an estimation of plant height.

To ensure that the remote-sensing approach effectively captures canopy temperature, we deployed ground-truthing temperature sensors (thermocouples) which were installed physically on plants so that we have an estimate of temperature as experienced by the plants. At flag leaf appearance, a total of 24 T-type thermocouples were installed throughout the trial in the flag leaves, with one mounted on a stick to measure air temperature at canopy height.

Economic Benefit to a Typical 500 Acre Wheat Enterprise:
The ability to deliver more productive and resilient varieties for the farmer depends on new technologies such as the one being developed in the proposal. By being able to rapidly screen breeding lines for their canopy health and performance under normal and stressful conditions, this new technology will support and strengthen the ability of the U of M wheat breeding program to deliver more rapidly better yielding varieties to growers. The proposal directly aims at increasing the yield potential, and therefore the profitability of the crop for the farmer.

Related Research:
This research is directly linked to the U of M wheat breeding program. Anderson and Sadok have recently received federal funding (USDA) for a graduate who would participate in UAV-based data capture activities.

In addition, the technology being developed has been already successfully tested on other small grain crops such as oats (Lopez et al. 2022). This research directly connects to Dr. Sadok's international research program which aims to help breeders develop wheat cultivars equipped with canopy traits that maximize yield gains under different water availability regimes in the Middle-East and Australia (Schoppach et al. 2017; Sadok et al. 2019; Tamang et al. 2019; Sadok and Schoppach 2019; Schoppach et al. 2020; Monnens and Sadok 2020). In the future, we expect that this work will benefit efforts to enhance resistance not only to weather stressors (drought, heat, etc) but also to pathogens such as rusts and FHB.

Recommended Future Research:
Future research will focus on further developing the data analytics pipeline with the goal of enabling the detection of genetic loci associated with desirable canopy temperature traits. These loci will be evaluated against genetic loci that we detected in our research on wheat canopy conductance, which we recently published (Tamang et al. 2022). Favorable alleles at these genetic loci will be integrated in the U of M breeding pipeline and pyramided with other desirable genes to improve the yield potential of the next generation of varieties that will be released by the breeding program.

Publications:

- Lopez, J.R., Tamang, B.G., Monnens, D.M., Smith, K.P. & Sadok, W. (2022). Canopy cooling traits associated with yield performance in heat-stressed oat. European Journal of Agronomy 139, 126555.
- Monnens, D.M., & Sadok, W. (2020). Whole plant hydraulics, water saving, and drought tolerance: a triptych for crop resilience in a drier world. Annual Plant Reviews, 3(4), 661-698.
- Sadok, W., Schoppach, R., Ghanem, M. E., Zucca, C., & Sinclair, T. R. (2019). Wheat drought-tolerance to enhance food security in Tunisia, birthplace of the Arab Spring. European Journal of Agronomy, 107, 1-9.
- Schoppach, R., Fleury, D., Sinclair, T. R., & Sadok, W. (2017). Transpiration sensitivity to evaporative demand across 120 years of breeding of australian wheat cultivars. Journal of Agronomy and Crop Science, 203(3), 219-226.
- Tamang, B. G., Schoppach, R., Monnens, D., Steffenson, B. J., Anderson, J. A., & Sadok, W. (2019). Variability in temperature-independent transpiration responses to evaporative demand correlate with nighttime water use and its circadian control across diverse wheat populations. Planta, 250, 115-127.
- Tamang, B. G., Monnens, D., Steffenson, B. J., Anderson, J. A., & Sadok, W. (2022). The genetic basis of transpiration sensitivity to vapor pressure deficit in wheat. Physiologia Plantarum, 174 (5) e13572.

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Figure 1. Yield performance of the 468 breeding lines in the 2022 PYT conducted at the St. Paul campus of the U of M. Breeding lines are ranked from the highest to the lowest-yielding. Due to the lack of space, only a fraction of genotype names is indicated.

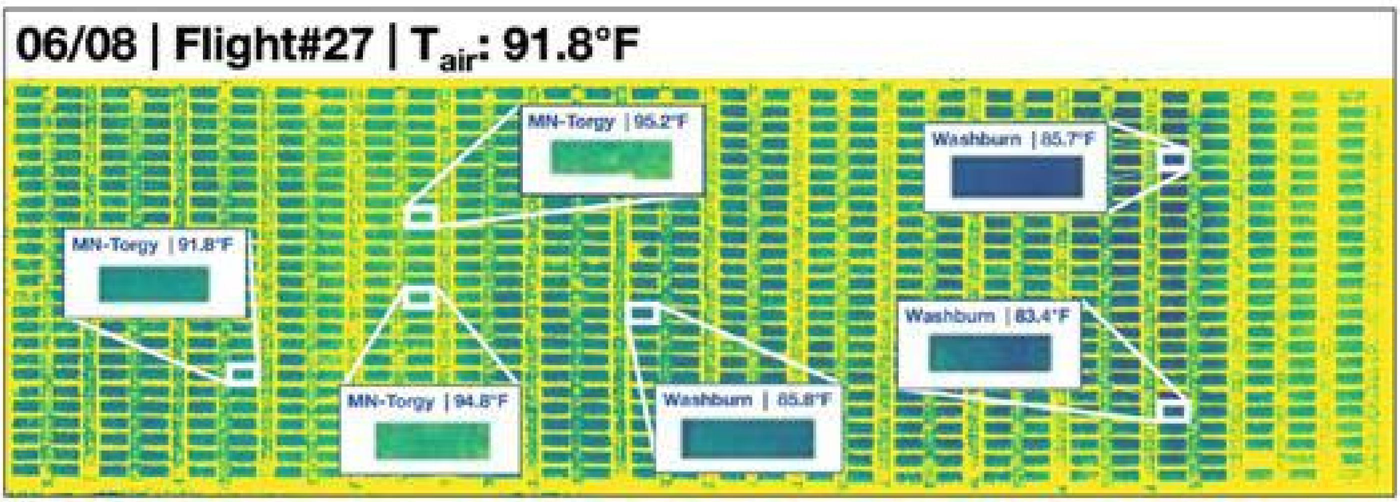

Figure 2. A composite color-coded thermal image showing consistent differences in canopy temperature between two check cultivars, MN-Torgy and MN-Washburn, measured on June 8th 2021 under hot and droughty conditions. Cultivar MN-Washburn consistently exhibited a cooler canopy (dark blue plots, compare to green-yellow plots) indicating a better ability to protect itself from excessive heat stress. The image spans the entire yield trial.

Evaluating the impact of drain spacing and fungicide seed treatment on common root rot and Fusarium crown rot in wheat

Ashok Chanda, Dept. of Plant Pathology & Northwest Research and Outreach Center, University of Minnesota; Jochum Wiersma, Dept. of Agronomy and Plant Genetics & Northwest Research and Outreach Center, University of Minnesota; Jeffrey Strock, Dept. of Soil, Water & Climate & Southwest Research and Outreach Center, University of Minnesota; Lindsay Pease, Dept. of Soil, Water & Climate Northwest Research and Outreach Center & University of Minnesota

Project Period: January 01, 2022 – December 31, 2022

Research Question/Objectives:
The objectives of this research were to evaluate the impact of tile drain spacing and fungicide seed treatments on 1) stand establishment, 2) relative incidence and severity of Fusarium crown rot (FCR) and common root rot (CRR), and 3) grain yield of wheat.

Results:
In 2022, the Northwest Research and Outreach Center (NWROC), Crookston, MN, recorded a total rainfall of 5.82 in. and 4.73 in. for April and May, much greater than the 10-year averages of 1.57 in. and 2.49 in., respectively. The wet conditions early in the year resulted in a delayed planting date; moreover, the rest of the growing season was slightly drier than the 10-year average, with only a few rainfall events occurring in June, July, and August. Additionally, the beginning of June was slightly cooler than average, but temperatures returned to average or slightly above average for the rest of June, July, and August.

Plant stands averaged 1.34 million plants per acre; there were no significant ($P < 0.05$) differences among treatments. There were significant differences for canopy coverage estimates. On June 7, seed treated with Stamina 4F had a canopy coverage of 30%, greater than the 28.6% of the non-treated seed. Seed treated with Stamina F4 continued to have a greater canopy coverage than the non-treated seed for the remaining evaluation dates; however, differences were not statistically significant (Figure 1). Regarding drainage spacing, significant differences were present for all three evaluation dates. Initially, on June 7, the 15-ft spacing resulted in the highest canopy coverage, and the lowest was the 25-ft and 40-ft spacing. By June 22, the 40-ft spacing was statistically lower than all other drain spacings (Figure 2). Root rot incidence and severity have yet to be evaluated.

Application and Use:
Both excess and limited soil moisture can impact root rot diseases in wheat. Dry soil conditions can favor development of CRR, caused by Bipolaris sorokiniana under cooler soil conditions, or FCR, caused by Fusarium spp. under warmer soil conditions. Dry conditions during the latter part of the growing season can aggravate FCR. Use of appropriate fungicide seed treatment under variable soil moisture conditions under artificial inoculation will enable us to understand the benefit of seed treatments for improving plant health and preserve yield.

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Table 1. Effect of fungicide seed treatments and drain tile spacing on stand establishment, growth progress, grain moisture, and yield of wheat in a field trial infested with *C. sativus* and *F. graminearum* at the University of Minnesota, Northwest Research and Outreach Center, Crookston, MN, sown on May 17, 2022.

Seed Treatment and Drain Spacing	Plant Stand (x 1,000,000) [z]	AUGPS [y]	Moisture (%)	Grain Yield (bu/A) [x]
Nontreated				
15 feet	1.30	1411	11.9	80.9
25 feet	1.36	1307	11.9	80.3
40 feet	1.22	1200	12.4	84.5
60 feet	1.43	1365	11.9	78.3
Non-drained	1.42	1365	12.1	83.7
Stamina F4				
15 feet	1.28	1481	12.1	79.3
25 feet	1.27	1342	12.1	78.9
40 feet	1.28	1210	12.8	84.2
60 feet	1.40	1430	12.2	79.5
Non-drained	1.41	1437	12.2	84.4
HSD [w]	NS	NS	NS	NS
P- value	0.8590	0.7934	0.3264	0.9261

Seed Treatment (Vertical Factor) [v]				
Nontreated	1.35	1330	12.1	81.5
Stamina 4F	1.33	1380	12.3	81.3
HSD	NS	NS	NS	NS
P- value	0.6633	0.1155	0.7119	0.8670

Drain Spacing (Horizontal factor) [u]				
15 feet	1.29	1446 a	12.0 b	80.1 ab
25 feet	1.31	1325 ab	12.0 b	79.6 ab
40 feet	1.25	1205 b	12.6 a	84.4 a
60 feet	1.42	1398 a	12.1 b	78.9 b
Non-drained	1.41	1401 a	12.2 b	84.1 a
HSD	NS	129	0.2	5.0
P- value	0.0916	**0.0015**	**0.0013**	**0.0134**

[z] Million plants per acre; evaluated on June 2, 16 days after planting (DAP)

[y] Area under growth progress stairs (AUGPS); mid-point combination of canopy coverage estimates into a single value.

[x] Bushels per acre (bu/A) adjusted for 13.5% moisture

[w] For each column, numbers followed by the same letter are not significantly different according to Tukey's honest significant difference (HSD); NS = not significantly different

[v] Values represent mean of 30 plots (6 replicates across 5 drain spacing treatments)

[u] Values represent mean of 12 plots (6 replicates across 2 fungicide seed treatments)

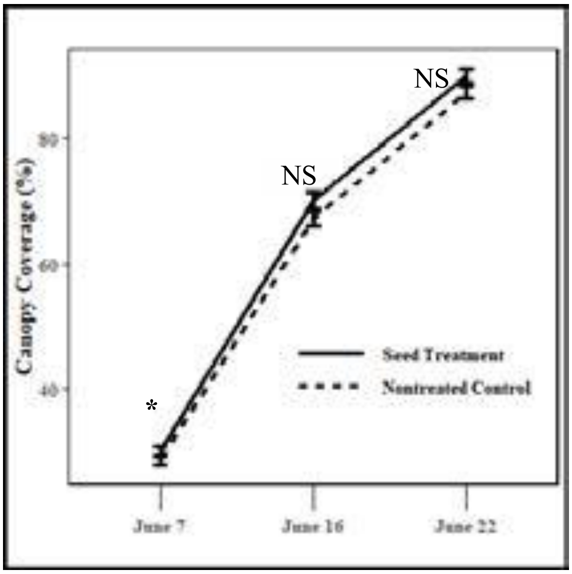

Figure 1. Canopy coverage estimates of wheat
h a seed treatment (Stamina F4 [4.6 fl
cwt]) compared to nontreated seed sown
May 17 at the University of Minnesota,
VROC, Crookston, MN. There were
nificant (P = 0.014) differences among

significant.

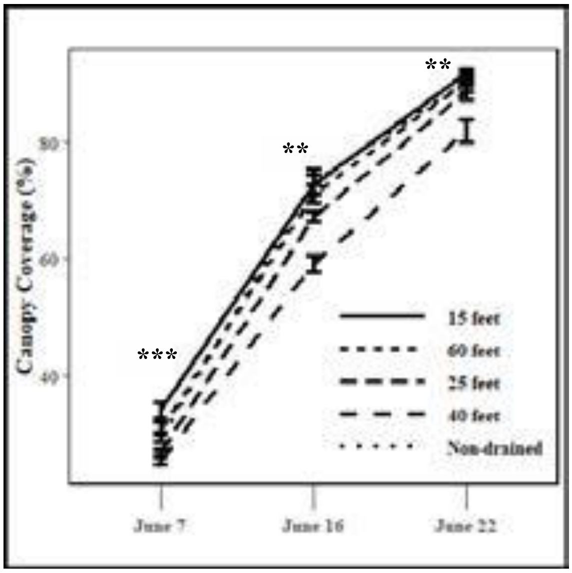

Figure 2. Canopy coverage estimates of wheat sown on a plot area consisting of non-drained and drained areas; drainage installed with 15-, 25-, 40-, and 60-foot spacings. Plots were planted May 17 at the University of Minnesota, NWROC, Crookston, MN. There

drain spacing on June 7, June 16, and June 22.

Materials and Methods:

The trial was established at the University of Minnesota NWROC, Crookston, MN, on a Hegne silty clay loam, classified as poorly drained soil. The research plot area, established in 2001, consists of a combination of non-drained and drained experimental units. Subsurface drainage is installed at a depth of about 40 inches. The site consists of five drain spacings: 15, 25, 40, and 60 ft. apart and a control which is undrained, representing drainage intensities (water removal rates) of 0.25, 0.50, and 0.75 in/d.

Field plots were fertilized for optimal yield. Prior to planting, soil was infested with Fusarium graminearum on whole corn at 12.5 kg/A and Cochliobolus sativus (syn. Bipolaris sorokiniana) on whole barley at 9.5 kg/A by hand-broadcasting in plots and incorporated with a Rau seedbed finisher. Treatments were arranged in a randomized strip-plot design with 6 replicates for each drain spacing x treatment combination.

The trial was sown in 10-row plots (5.5-ft wide x 600-ft long) on May 17 at a seeding rate of 38 seeds per square foot with the 'Torgy' wheat variety. The seeding rate was increased to account for late planting. Seed was treated with Stamina F4 Cereals (Fluxapyroxad + Pyraclostrobin + Triticonazole + Metalaxyl) at a rate of 4.6 fl oz/cwt. The nontreated control did not include any seed treatment and was planted as bare seed. Stand counts were done on June 2, 16 days after planting (DAP) by counting the number of plants within a 3-ft section in the center four rows of each plot. Canopy coverage was estimated on June 7 (21 DAP), June 16 (30 DAP), and June 22 (36 DAP) by analyzing digital photographs with the open-source software Foliage (v 1.0, Patrignani, 2020). Canopy coverage estimates were used to calculate plant growth progress (area under growth progress stairs [AUGPS]). Plants were collected (n=40) from each plot on August 8 and stored at -20°C for further evaluation of disease incidence and severity.

Each plot was harvested mechanically on August 23. Data were collected for moisture, test weight, and yield during harvest with a calibrated Wintersteiger plot combine. Statistical analysis was conducted in R (v 4.2.0, R Core Team 2022) with the package agricolae (v 1.3-5). The strip.plot function was used for the analysis of a split-plot design, which is divided into three parts: the vertical-factor analysis, the horizontal-factor analysis, and the interaction analysis. Tukey's honest significant difference (HSD) was used for post hoc analysis at a 0.05 level of significance with the respective error terms.

Accelerated Breeding for Resistance to Fusarium Head Blight

Karl D. Glover

Project Period: January 1, 2022 – December 31, 2022

Research Question/Objectives:
Complete resistance to Fusarium Head Blight (FHB) is unavailable, yet genetic variability for resistance is well documented. Steady progress toward increasing resistance levels has been demonstrated by breeding programs through implementation of largely repeatable FHB screening procedures. Breeding programs must sustain efforts to simultaneously select resistant materials with desirable agronomic characteristics. The objective of this project is to use traditional plant breeding and selection techniques to develop hard red spring wheat germplasm and cultivars that possess agronomic characteristics worthy of release in addition to acceptable levels of FHB resistance.

Results:
Entries retained in the advanced yield trial (AYT) are generally at least moderately resistant to FHB. Those that do not perform adequately are discarded after the first year of AYT observation. Results of the 2022 AYT are presented in Table 1. Thirty-seven experimental breeding lines were tested along with eleven check cultivars during the 2022 growing season. Of the thirty-seven experimental lines, sixteen had FHB disease index (DIS) values that were lower than the test average. Among these entries, six produced more grain than average. Among the six, test weight of four entries was higher than average, and protein content of two (SD5087 and SD5090) were also greater than average. Although protein content of SD4843 was less than average, it will likely be released in November 2022. Certified seed production will take place during the 2023 growing season.

Application/Use:
With the progression of time, increases in FHB resistance levels should help to prevent devastating loses to growers caused by severe FHB outbreaks.

Materials and Methods:
Focused efforts to increase resistance began within this program after the 1993 FHB epidemic in the spring wheat production region. Both mist-irrigated greenhouse and field screening nurseries were established, and disease evaluation methods were developed. Breeding materials are evaluated for FHB resistance using three generations per year: two in the greenhouse and one in the field. We have the capacity to screen as many as 4,500 individual hills in the greenhouse (over two winter seasons). We can also have as many as 4 acres in the field under mist-irrigation. Both the field and greenhouse nurseries are inoculated with grain spawn (corn that is infested with the causal fungus) and spore suspensions. Mist-irrigation is used to provide a favorable environment for infection. Approximately 50 percent of the experimental populations possess Fhb1 as a source of resistance. Most of what remains are crosses with various “field resistant” advanced breeding lines.

Experimental materials are advanced through the program in the following fashion:

Year 1	Field	Space-planted F_2 populations
Year 1	Fall greenhouse	$F_{2:3}$ hills
Year 1	Spring greenhouse	$F_{3:4}$ hills
Year 2	Field	$F_{4:5}$ progeny rows
Year 2	Off-season Nursery	$F_{5:6}$ progeny rows
Year 3	Field	$F_{5:7}$ Yield Trials (1 replication, 2 locations)
Year 4	Field	$F_{5:8}$ Yield Trials (2 replications, 5 locations)
Year 5	Field	Advanced Yield Trials (3 reps, 10 locations)

F_2 populations are planted in the field and individual plants are selected. These are advanced to the fall greenhouse where seed from each plant is sown as individual $F_{2:3}$ hills and evaluated for FHB resistance. Four plants from each of the top 25% of the hills are advanced to the spring greenhouse. They are sown as individual $F_{3:4}$ hills and evaluated for FHB resistance. Those with FHB resistance nearly equal to or better than 'Brick' are then advanced to the mist-irrigated field nursery as $F_{4:5}$ progeny rows. They are evaluated again for resistance and general agronomic performance. Plants are selected within the superior rows and sent to New Zealand as $F_{5:6}$ progeny rows for seed increase. A portion of seed from each selected plant is also grown in the fall greenhouse to confirm its resistance.

If the FHB resistance of an $F_{5:6}$ line is confirmed, then the respective progeny row is harvested in New Zealand. In the following South Dakota field season, selected lines are tested in a two replication, multi-location yield trial. Those that have agronomic performance and yield similar to current cultivars are included in more advanced, multi-location, replicated yield trials the following year. In year 5, lines advanced through this portion of the program are included in the AYT along with entries from the traditional portion of the program. Performance data with respect to Disease Index, along with agronomic potential from the 2022 AYT are presented in Table 1.

Economic Benefit to a Typical 500 Acre Wheat Enterprise:
The presence of FHB inoculum within fields and favorable weather conditions are just two factors that heavily influence whether this disease becomes problematic. Immediate economic benefits are therefore difficult to assess. When conditions become favorable for disease development, however, cultivars with elevated FHB resistance levels can help to reduce potentially serious grower losses.

Publications:
Glover K. D., J. L. Kleinjan, C. Graham, S. Ali, Y. Jin, J. A. Ingemansen, E. B. Turnipseed, and L. Dykes. 2021. Registration of 'Ascend-SD' Hard Red Spring Wheat. Journal of Plant Registrations.

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ENTRY	DIS INDEX	YIELD (BU/AC)	TW (LB/BU)	PROTEIN (%)	HEADING (D > 6/1)	HEIGHT (INCHES)
BRICK	10.9	33.9	62	16	27.3	31.4
SD4930	12.5	42.5	59.8	15.1	30.9	30.2
ASCEND-SD	12.6	42.1	60.9	16.1	31.3	32.1
SD4949	12.9	37.8	60.7	17	31.5	32.3
SD5074	13.1	34.1	60	16.7	30.2	31.6
BOOST	13.2	34.8	59.8	16.2	31.8	31.2
SD5090	13.5	40.7	61.6	16	30.6	29.4
LCS-TRIGGER	14.1	40.9	60.6	14.5	35.2	30.9
SD4925	14.2	35.4	61.2	16.6	27.9	28.9
DRIVER	14.3	40.3	61.9	15.6	31	31.1
FOREFRONT	14.3	34.9	61	15.8	27.5	33.4
SD4843	14.4	42.6	62	15.2	30.3	30.1
SY-VALDA	14.4	39.2	60.7	15.6	30.4	28.9
PREVAIL	14.5	38.8	60.9	15.2	29.6	30
SD5080	14.6	37	62.6	15.7	29.8	30
SD5060	14.7	36.9	60.5	15.8	30.2	29.1
SD5079	14.8	35.6	62.4	15.9	30.1	29.9
SD5087	14.9	38.9	61.6	16.3	29.9	30.1
SD4905	15.1	42	60.5	16.1	29.1	30.2
SD4985	15.4	38.4	61.4	15.8	30.7	28.8
SD5049	15.4	38	61.1	15.5	29.6	26.8
SD4944	15.6	37.5	59.7	16.3	33.9	28.7
SD5092	15.6	36.8	60.1	16.7	31.5	31.4
SD5095	15.6	37.8	62.2	15.8	31.8	29.5
SURPASS	15.7	37.2	60.4	16.1	28.4	30.1
SD5051	16.1	38.2	61.2	15.6	28.9	28.2
SD5091	16.1	38.9	61.7	16.1	29.9	29.3
SD4998	16.3	39	60.7	15.7	31	29.2
SD4894	16.4	38.3	60.9	16.3	27.9	31.1
SD4991	16.4	38.2	61	15.8	28.7	29
SD5059	16.5	40	59.5	15.6	32.3	29.8
SD5072	16.5	38.5	61.2	16	30.8	30.5
SD5043	16.6	38.2	61.1	16.3	30.9	27.8
SD5082	16.6	36.8	62.6	15.6	30.1	29.4
SD5040	16.7	37.4	61.5	15.8	28.7	28.8
SD5050	16.7	38.8	61.6	15.6	28.8	27.3
ADVANCE	16.8	38.2	61.1	15.3	31.4	27.8
SD4924	17	36	61	15.8	27.6	30.2
SD5031	17.3	38	60.2	16.4	30	27.6
SD5076	17.3	35.1	61.4	16.5	29.2	30.2
SD5032	17.4	39	60.7	15.8	29.7	27.2
SD5030	17.5	36.9	61.1	16	30.8	26
SD4904	18	40	59.9	15.6	30.4	30.1
SD5033	18	38.1	59.8	16.2	29.8	27.7
SD5029	18.1	36.7	59.4	16.7	30.9	26.4
SD5037	19.6	38.7	60.5	15.7	32.1	29
TRAVERSE	20.7	36.3	57.6	15.4	28.3	32.4
SD5028	20.8	37.7	58.8	16.2	31.1	26.7
MEAN	15.75	38.06	60.84	15.91	30.19	29.53
LSD (0.05)	3.27	0.93	1.15	0.17	0.65	0.61
cv	18.24	5.09	1.11	2.13	2.68	3.13

Table 1. South Dakota State University advanced yield trial spring wheat entries ranked according to FHB disease index values (lowest to highest – collected at Brookings) presented along with agronomic data obtained from three replication trials conducted at ten test environments in 2022.

Wheat Multi-Trait Predictions: A Quantitative, Genotype x Environment (GxE) Approach to Supporting Minnesota Wheat Breeding and Farmer Varietal Selections

Kevin Silverstein (PI)
Yuan Chai (co-PI)
James Anderson (co-PI)

Project Period: 02/01/2022 – 12/31/2023

Research Question/Objectives:
A perennial challenge faced by wheat breeders and producers is to identify and select the best performing varieties for each location. A high-yielding variety at one location during one season may not perform well at another location and/or another season, exemplifying the strong effects of Variety (Genotype) by Environment (GxE) interactions on crop performance. In this project, researchers at the UMN CFANS GEMS Informatics Center (led by Dr. Yuan Chai and Dr. Kevin Silverstein), in collaboration with breeder Dr. Jim Anderson from the Department of Agronomy and Plant Genetics, are developing a wheat trait prediction tool to intelligently combine crop performance data, genomic information, environmental conditions, and their GxE interactions to accurately predict the performance of different varieties under different environments. This tool will allow simultaneous optimization in the selection of relevant traits under different environments, including grain yield, protein content, straw strength, heading date, height, and disease resistance.

Results:
Phenotype data from field trials: A database of wheat grain yields for 183 varieties and experimental lines grown in one or more years and up to 15 locations per year (Figure 1) was assembled from annual performance data files maintained by the UMN wheat breeding program. At this time, we have permission from the developers to include 135 varieties/lines in this study and, subject to resolving data privacy concerns, may be able to include an additional 28 varieties. End-use quality data from these same lines, grown at 2 locations per year and produced by the USDA-ARS Hard Spring and Durum Wheat Quality Laboratory (HSDWQL) in Fargo, has also been assembled.

MN wheat varieties genotyping results: For the panel of selected wheat varieties, GBS (Genotyping-by-Sequencing) resulted in over 11,000 SNP markers across the genome in each of the 128 panel lines that met stringent data quality thresholds. There was coverage across all the chromosomes. The distribution of SNP markers on each chromosome is shown in Figure 2. The underrepresentation of the D-genome is typical for wheat and was expected. The number of SNP markers obtained was about four times higher than we typically use in our prediction work, so marker coverage for genomic prediction should be excellent.

Environmental data and crop growth modeling: The wheat grain yield data from 15 trial locations and multiple years was used to select weather and soil features that were most important for yield prediction. A gridded map was produced for Minnesota showing environmental similarity of different zones with the trial sites using only the selected environmental features for comparison as shown in Figure 3. The spatially-explicit weather data was averaged over the preceding three years for more reliability as shown by Neyhart et al. (2022) to generate the environmental similarity grid. The idea is to be able to predict which of the already-tested lines would perform best in new untested locations that are similar in agroecological (i.e., soil and climate) terms to the trial sites. Further efforts to generate and test trait response models for wheat that incorporate the genetic effects, and their environmental interactions (i.e., G x E), are ongoing.

Application/Use:
Faster varieties to market: In a typical wheat breeding cycle (as illustrated in Figure 4), it takes 9 years starting from the first cross to create a commercial variety. By the time the variety is released, it is already slightly out of date due to rapid climate changes, novel pest pressures, and changing market forces. It is anticipated that our novel prediction pipeline will shave off 2 years from the breeding cycle, for a total of 7 years, which would allow growers to gain two extra growing seasons when the germplasm's design objectives will be most relevant.

Seeds better suited to growers' field conditions:
Currently our prediction tool is anticipated to make excellent forecasts for how well novel wheat varieties will grow at each of the breeders' test sites.

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To aid growers' decision making we are developing an environmental similarity zone matcher that links growers' fields to the most similar test site (according to the soil and weather characteristics of each location). At the conclusion of this funding cycle, growers will be able to determine how similar their fields are to a well-tested location, and then readily identify the best-performing varieties at that location. The strength of the similarity of their field to the best-matched test site will help in gauging confidence in the prediction.

Materials and Methods:
Phenotyping: Yield trial nurseries were grown as 50-80 sq. ft. plots with 3 replications per entry. Trial nurseries (up to 15 locations per year) are located across the wheat growing areas in the state of Minnesota. Spatial correction was performed within each location prior to calculating entry means.

Genotyping: Genotyping by sequencing (GBS) uses next-generation DNA sequence technology (Illumina) to obtain single nucleotide polymorphism (SNP) markers across the entire genome. It is a fast and cost-effective method to genotype breeding populations with thousands of DNA markers that can be used in genomic selection. A panel of 128 cultivars and advanced experimental breeding lines phenotyped in yield trials in a minimum of 13 environments, and up to 138 environments, were genotyped at the University of Minnesota's Genomics Center (UMGC) using GBS. The short DNA sequence reads from each individual line were mapped to the Chinese Spring V2.1 reference genome (Zhu et al. 2021) to find the SNP markers and determine their physical positions in the genome.

Crop growth modeling: A coding pipeline has been designed to source weather data for each trial site and year combination from the GEMS Weather API. The soil data for each trial site was obtained by querying the GEMS Soil API. The pipeline uses empirical planting dates and weather parameters to predict phenological stages for wheat using the BBCH growing scale. The weather parameters were summarized over four broad phenological stages- early vegetative, late vegetative, flowering, and grain fill. The relevant soil and weather environmental covariates (EC) per trait were determined using a stepwise linear regression model or a lasso regression grid search model with cross validation assuming a fixed effect for genotypes. A covariance matrix was generated for the selected environmental covariates that represents how similar or dissimilar the sites are to each other. The full model utilizes this EC matrix and a genomic similarity matrix generated from the genotyping data, to assess the trait-performance effect of the genotypes, the environments, and their interaction on the traits of interest, as previously illustrated by Neyhart et al. (2022) for barley. We used a leave-one-location-out approach for testing prediction accuracy.

Economic Benefit to a Typical 500 Acre Wheat Enterprise:
The spring wheat multi-trait prediction tool developed by this project will improve the cost-effectiveness of regional spring wheat breeding programs by enabling breeders to select for varieties with a higher likelihood of success for a number of commercially valuable traits. As a result, a typical 500 acre wheat enterprise in Minnesota will benefit from having earlier access to a wider selection of improved wheat varieties that are better matched to their local environmental conditions and changing market demands.

Related Research:
The model we have developed requires accurate weather data, soil characteristics, and crop calendar (planting date, harvest date) information for each location (training sites and farm query sites). The University of Minnesota's GEMS Informatics Center has invested substantial effort over the past few years into developing Application Programmer Interfaces (APIs) to make accessing this data easy, for any site on the globe. Both the multi-trait prediction tool and the API data retrieval tools are subject to on-going improvement. GEMS also has in-house hardware engineers who have developed sophisticated weather and soil sensor stations within our GEMS Sensing program. 2,200 sensing stations have already been deployed at various locations throughout the world, including across all of the ROCs (Research and Outreach Centers) located throughout Minnesota. Further, we have been working on multi-regression and Machine Learning algorithms that use satellite data to make more accurate estimates of important crop performance metrics , including crop emergence date and harvest date. When this line of research is more fully developed, we could use these phenology predictions to fill in missing data from our trial records, which in turn is likely to improve the accuracy of our multi-trait predictive tool.

Recommended Future Research:
The effectiveness of our wheat multi-trait prediction tool depends on both the quantity and quality of the genotype, phenotype, and environment input data. To improve our wheat multi-trait prediction tool, future research would benefit from collecting more detailed primary data from more varieties and more locations across different environmental conditions.

In addition, further funds can also be used to support the development of this tool into an application programming interface (API) to enable breeders to easily incorporate this tool into their current breeding programs.

GEMS has a development approach that creates ever-improving predictive tools. To be cost-effective within the funding available for this project, we are adapting and fine tuning our core trait modeling framework that worked well for barley, and applying that to wheat. However, in a subsequent version of the tool we believe that we can offer even more value to growers by making changes to the fundamental algorithm itself. Currently, our internal environment matrix is indexed by field trial location. This works very well for breeders since they are often planting their trials at the same fixed sites. But it has less value for making predictions at new field locations. This model identifies variety x new location suitability indirectly because it requires making environmental similarity comparisons back to one of the trained locations. In a future version of this tool we plan to reconfigure the central covariance matrix (and thus the associated predictive analytic inferences that can be made) to be indexed by environmental characteristics (e.g., temperature, soil water holding capacity, pH, soil porosity) rather than physical trial locations per se. This will require a full recalibration of our modeling framework, but such a re-tooling will allow us to directly make predictions for any farmer's field throughout Minnesota (as long as the measured value for each environmental characteristic falls within the bounds of what was observed during training the model – i.e., does not require extrapolating to extreme outliers).

Reference:

Zhu, T., Wang, L., Rimbert, H., Rodriguez, J.C., Deal, K.R., De Oliveira, R., Choulet, F., Keeble Gagnère, G., Tibbits, J., Rogers, J., Eversole, K., Appels, R., Gu, Y.Q., Mascher, M., Dvorak, J. and Luo, M. C. (2021), Optical maps refine the bread wheat Triticum aestivum cv Chinese Spring genome assembly. The Plant Journal. Accepted Author Manuscript. https://doi.org/10.1111/tpj.15289

Neyhart J.L., Silverstein K.A.T., Smith K.P. (2022), Accurate predictions of barley phenotypes using genomewide markers and environmental covariates. Crop Science. DOI: 10.1002/csc2.20782

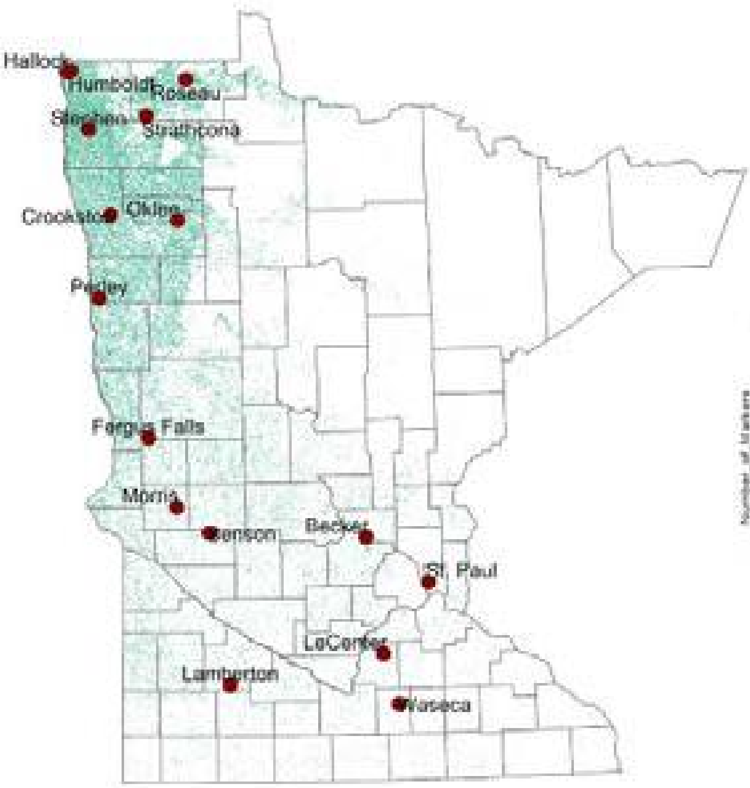

Figure 1: MN spring wheat phenotypic data trial sites. The green pixels represent wheat growing areas in 2020 and the red dots are the trial sites used by this study to source our phenotypic (i.e., trail performance) data.

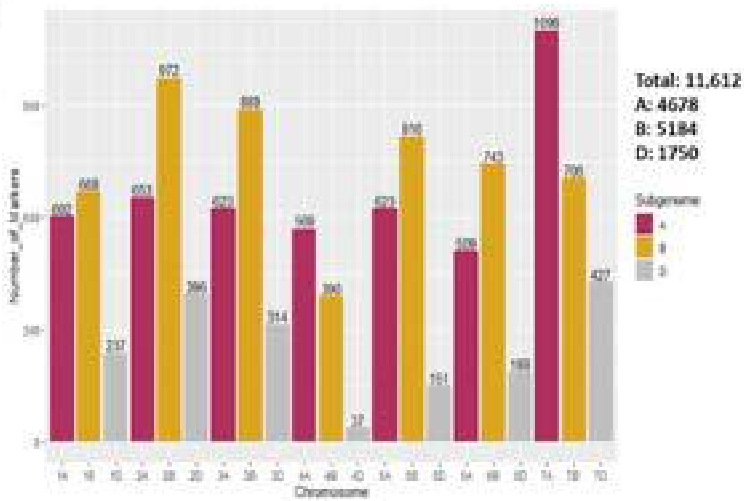

Figure 2: Number of markers by chromosome. Chromosomes are shown on the x-axis and the number of markers on the y-axis. The A-subgenome is depicted in maroon, the B-subgenome in gold, and the D-subgenome in gray. The total number of markers for the whole genome, and for each of the three subgenomes are listed to the right of the graph.

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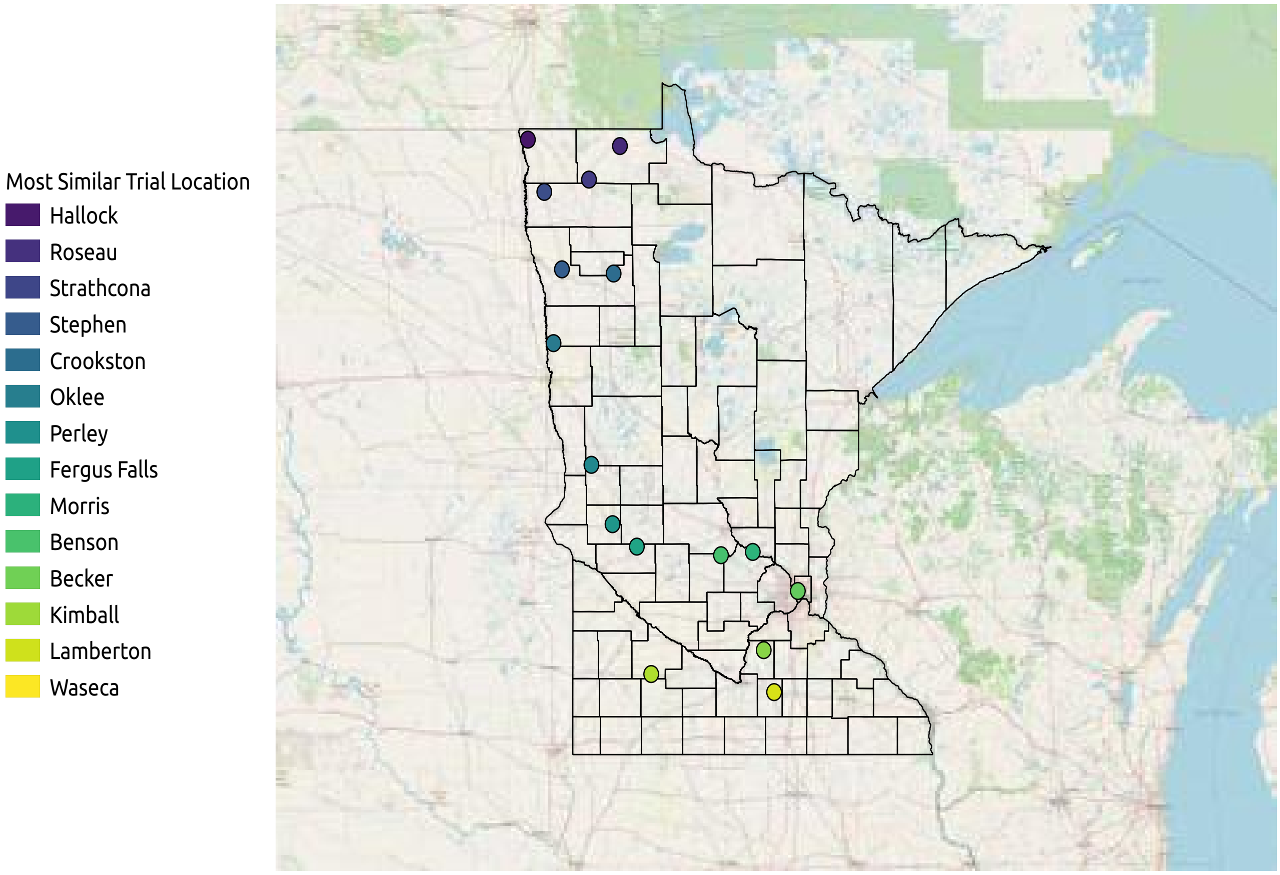

Figure 3: Environmental similarity map of Minnesota. A gridded map of Minnesota showing the environmental similarity of locations throughout the state with the trial sites used for this study. Each grid cell is 9 km2 in size and the color key for location similarity is given on the left of the map. Environmental features important for wheat yield were selected using the lasso grid search algorithm. Similarity of zones was based on Spearman's rank correlation calculation. The zones shown in this map are preliminary as we are still surveying different correlation metrics and feature selection protocol. Final procedures will be settled after conferring with our breeding team and growers.

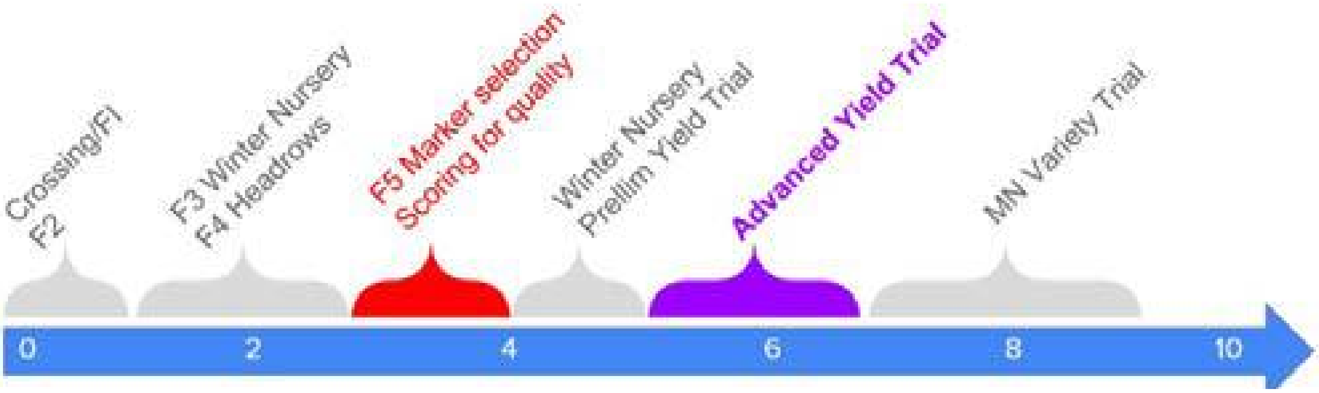

Figure 4. Typical MN wheat variety breeding cycle. The advancements in this research project are expected to shave a year off each of the activities highlighted in red and purple. In the red activity, there are far too many lines to do a complete phenotypic scoring. However, genotyping them all is easy. And based on those genotypes, our tool can produce very accurate phenotypic predictions. In the purple activity, our phenotypic predictions will greatly speed up the selection of the final parents to pass on to the next cycle.

University of Minnesota Wheat Breeding Program

James A. Anderson & Jochum Wiersma
Project Period: January 1, 2022 – December 31, 2022

Research Question/Objectives:
This is a continuation of the U of MN spring wheat breeding program with the objectives: 1) Develop improved varieties and germplasm combining high grain yield, disease resistance, and end-use quality; and 2) Provide performance data on wheat varieties adapted to the state of Minnesota.

Results:
During the 2021/2022 crossing cycle, 235 crosses were made. The 2022 State Variety Trial, which contained 45 released varieties, 13 University of Minnesota experimental lines, 4 experimental lines from other programs, and 3 long term checks was evaluated at 14 locations. Another 230 advanced experimental lines were evaluated in advanced yield trials at up to 10 locations and 468 lines were evaluated in preliminary yield trials at 3 locations. A total of 8,779 yield plots were harvested in 2022. Fusarium-inoculated, misted nurseries were established at Crookston and St. Paul. An inoculated leaf and stem rust nursery was conducted at St. Paul. DNA sequence information was obtained from 3,072 pre-yield trial lines and their FHB resistance and dough mixing properties were predicted based on a training set of 210 lines and their 55 parents. The predictions based on DNA sequence information were used to help select the 468 preliminary yield trial lines from the 3,072 candidate lines, therefore avoiding more expensive and time-consuming field-based evaluations on more than 2,000 lines with low genetic potential. Data from the yield and disease nurseries are summarized and published in Prairie Grains and the MAES's 2022 Minnesota Field Crop Variety Trials (https://varietytrials.umn.edu).

Experimental line MN15005-4 (Prosper/MN08301-6//Norden) was released as MN-Rothsay in 2022. MN-Rothsay has excellent grain yields, very good straw strength, and average grain protein. Disease resistance and baking quality are acceptable. See Table 1 for comparison of MN-Rothsay with other varieties.

Variety	Release Yr.	% of MN Acreage	Grain Yield (% of mean) 2022	2 Yr	3 Yr	HD d	HT in.	Straw Str. 1–9	Test Wt (lbs/bu) 2 yr	Protein (%) 2 yr	Baking Quality 1–9	PHS 1–9	Leaf Rust 1–9	Bacterial Leaf Str. 1–9	Scab 1–9
MN-Rothsay	**2022**	**–**	**102**	**103**	**104**	**51.4**	**25.4**	**3**	**60.7**	**14.8**	**5**	**2**	**4**	**4**	**4**
SY Valda	2015	11.0	104	103	104	50.4	25.2	5	60.5	14.4	6	2	4	4	4
Shelly	2016	4.0	103	103	103	50.9	25.7	5	60.6	14.4	5	1	5	6	4
AP Murdock	2020	7.6	103	98	102	48.8	25.0	5	60.2	14.5	5	1	3	4	7
MN-Torgy	2020	21.7	100	100	102	50.7	26.1	4	61.0	15.2	4	1	3	3	3
WB9590	2017	19.4	101	99	101	48.6	23.9	3	60.4	15.5	4	1	6	6	7
WB9479	2017	7.9	97	95	96	48.6	24.7	3	60.3	15.9	2	1	6	6	7
Linkert	2013	6.3	93	94	93	49.5	25.8	2	61.3	15.7	1	1	3	5	5

Table 1. Comparison of MN-Rothsay and the seven most popular spring wheat varieties grown in MN. Entries are sorted based on grain yield (% of mean) over 42 environments since 2020. For traits scored on a 1-9 scale, 1 is best and 9 is worst.

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Application/Use:
Experimental lines that show improvement over currently available varieties are recommended for release. Improved germplasm is shared with other breeding programs in the region. Scientific information related to efficiency of breeding for particular criteria is presented at local, regional, national, and international meetings and published.

Materials and Methods:
Approximately 300 crosses are made per year. A winter nursery is used to advance early generation material when appropriate, saving 1-2 years during the process from crossing to variety release. Early generation selection for plant height and leaf rust and stem rust resistance is practiced in nurseries in St. Paul and Crookston. Approximately 400 new lines are evaluated in preliminary yield trials at 3 locations. Advanced yield trials - containing 170-180 experimental lines – are evaluated at 10-11 locations. All yield nurseries are grown as 50-80 sq. ft. plots. Misted, inoculated Fusarium head blight nurseries are grown at Crookston and St. Paul and an inoculated leaf and stem rust nursery is grown at St. Paul. The disease nurseries involve collaboration with agronomists and pathologists at Crookston and with personnel from the Plant Pathology Department and the USDA-ARS. Genomic prediction is used at the pre-yield trial stage to predict the performance of experimental lines based on DNA sequence information of related lines. This allows us to screen a larger number of lines than we could accommodate in our field trials and can help us find the rare lines that combine all the desired traits in a high yielding line.

Economic Benefit to a Typical 500 Acre Wheat Enterprise:
Choice of variety is one of the most important decisions growers make each year. The development of high-yielding varieties that are resistant to the prevalent diseases and have good end-use quality are necessary to increase grower profitability. As an example, a new variety that yields 4% higher will produce 3 extra bushels/acre in a field that averages 75 bu/A. At $8.75/bushel that equates to more than $13,000 in additional gross revenue for a 500-acre wheat enterprise.

Related Research:
These funds provide general support for our breeding & genetics program. Additional monetary support for breeding activities in 2022 came from the MN Small Grains Initiative via the Minnesota Agricultural Experiment Station, and the U.S. Wheat and Barley Scab Initiative via USDA-ARS.

Recommended Future Research:
This is an ongoing project and we expect to deploy drone-based phenotyping and expand our use of genomic prediction in 2022.

Publications:
Jordan, K.W., Peter J Bradbury, Z.R. Miller, M. Nyine, F. He, M. Fraser, J. Anderson, E. Mason, A. Katz, S. Pearce, A.H. Carter, S. Prather, M. Pumphrey, J. Chen, J. Cook, S. Liu, J.C. Rudd, Z. Wang, C. Chu, A.M.H. Ibrahim, J. Turkus, E. Olson, R. Nagarajan, B. Carver, L. Yan, E. Taagen, M. Sorrells, B. Ward, J. Ren, A. Akhunova, G. Bai, R. Bowden, J. Fiedler, J. Faris, J. Dubcovsky, M. Guttieri, G. Brown-Guedira, E. Buckler, J.-L. Jannink, E.D. Akhunov. 2021. Development of the Wheat Practical Haplotype Graph database as a resource for genotyping data storage and genotype imputation. G3, https://doi.org/10.1093/g3journal/jkab390

Zhang, J. A. Min, B.J. Steffenson, W.-H. Su, C.D. Hirsch, J. Anderson, J. Wei, Q. Ma, and C. Yang. 2022. Wheat-Net: An Automatic Dense Wheat Spike Segmentation Method Based on an Optimized Hybrid Task Cascade Model. Front. Plant Sci. https://doi.org/10.3389/fpls.2022.834938

Rauf, Y., C. Lan, M. Randhawa, R.P. Singh, J. Huerta-Espino, J. Anderson. 2022. Quantitative trait loci mapping reveals the complexity of adult plant resistance to leaf rust in spring wheat 'Copio'. Crop Sci. https://doi.org/10.1002/csc2.20728

Boakye, P.G., I. Kougblenou, T. Murai, A.Y. Okyere, J. Anderson, P. Bajgain, B. Philipp, B. LaPlante, S. Schlecht, C. Vogel, M. Carlson, L. Occhino, H. Stanislawski, S.S. Ray, and G.A. Annor. 2022. Impact of sourdough fermentation on FODMAPs and amylase-trypsin inhibitor levels in wheat dough. J. Cereal Sci. https://doi.org/10.1016/j.jcs.2022.103574

Breeding winter wheat varieties with FHB resistance and straw strength

Sunish K. Sehgal, Gazala Ameen, Peter Sexton

Project Period: January 1, 2022- December 31, 2022 (Year 1)

Research Question/Objectives:
Winter wheat (soft wheat and hard wheat) offers several advantages over spring wheat including a 20% yield increase and fits well with cover crop rotation, conserves soil moisture, improves water quality, reduces soil erosion, and builds soil structure and soil health. Winter wheat can provide an opportunity for MN farmers to adopt a fall crop in their rotation considering the above-discussed advantages. Therefore, there is a need to develop varieties with good Fusarium head blight resistance and straw strength that are well adapted to this region. The primary objectives of the project are to enhance the FHB resistance and straw strength in soft and hard winter wheat and release improved winter wheat varieties for the region.

Results:
Population development and Speed breeding: In March 2022 more than 100 hard winter wheat and 40 soft white wheat crosses were performed in the first year of the new project. The F1's from these crosses were vernalized and are currently growing to develop F2 populations. The F2 plants carrying Fhb1 or Fhb6 (based on markers screening) from each cross will then be advanced using the speed breeding technique to F4 for field selection (Figure 1).

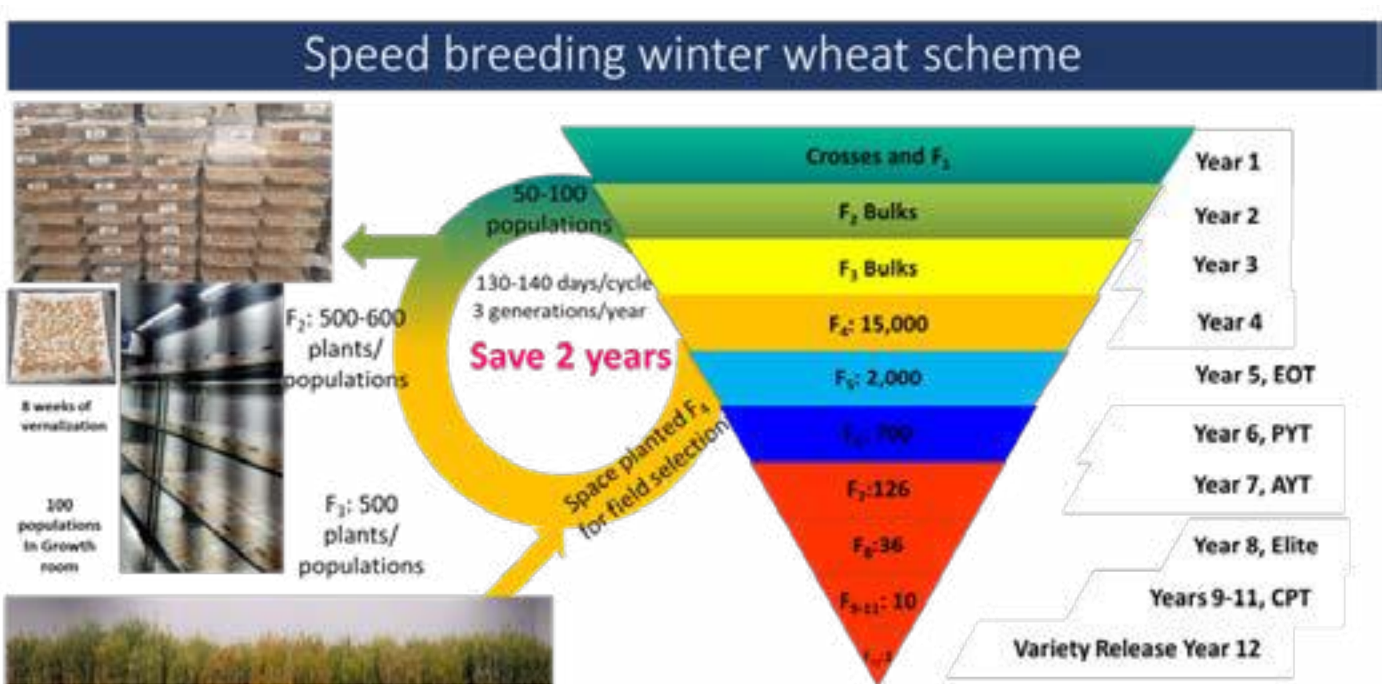

Figure1: Speed breeding scheme implemented in winter wheat breeding to shorten the variety development time.

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Selections in Segregating populations: Selections in space planted 79 F4 populations were made for dwarf height, tillering capacity, earliness, and rust resistance. Of these 79 populations, about 30 populations carried Fhb1 in a homozygous or heterozygous state. On average we selected 20-30 desirable plants from each of the 79 populations and advanced them to 4-row early observation trials (EOT is individual plant short rows) for the 2023 season to get an observation of yield potential and agronomic traits (Fig.1). The selected lines from EOT will be advanced to preliminary yield trials (PYT) in 2024.

Advanced and Elite yield trials: Hard winter Wheat advanced yield trial (AYT 2022) with 126 entries and Elite yield trial (Elite 2022) with 36 entries were performed at 7 and 8 locations, respectively, across SD. In AYT, the yield ranged from 28 bu/acre at Hayes to 115 bushels/acre at Selby, SD. Superior performing entries from AYT 2022 were advanced to Elite 2023 trials including two hard white wheat experimental lines SD20D063-2W and SD20D064-3W. Both the experimental lines have an early maturity with medium-short height, good winter hardiness, and average FHB resistance.

In the elite yield trials (Elite 2022) 30 new entries were evaluated along with six check cultivars. Of the 30 entries, 19 had a lower disease index than the trial average and eight entries had above-average grain yield (Table 1). Four entries SD18B055-2, SD19B164-3, SD19B108-3, and SD18B016-5 with good FHB resistance or below average height were advanced to state-wide crop performance trials (CPT) for the 2023 growing season. Few stable and high-yielding elite lines from CPT are also entered in MN winter wheat trials.

In Soft White Wheat (SWW) advanced yield trial (2022) we evaluated 20 entries including 5 check cultivars. The SWW trials were conducted at three locations along the I-29 corridor North Brookings, Aurora farm, and Beresford, SD. The average grain yield, test weight, and protein content were 59.1 bu/ac, 55.4 lb/bu, and 13.6 %, respectively. Drier weather in 2022 resulted in lower-than-expected test weight. Experimental line MI17W0133 toped the trials with a grain yield of 67.4 bu/acres.

GWAS of FHB resistance in SDSU germplasm: In this study, we evaluated a set of 257 breeding lines from the South Dakota State University (SDSU) breeding program to uncover the genetic basis of native FHB resistance in the US hard winter wheat. We conducted a multi-locus genome-wide association study (ML-GWAS) with 9,321 high-quality single-nucleotide polymorphisms (SNPs). A total of six distinct marker-trait associations (MTAs) were identified for the FHB disease index (DIS) on five different chromosomes including 2A, 2B, 3B, 4B, and 7A. Further, eight MTAs were identified for Fusarium-damaged kernels (FDK) on six chromosomes including 3B, 5A, 6B, 6D, 7A, and 7B. Out of the 14 significant MTAs, 10 were found in the proximity of previously reported regions for FHB resistance in different wheat classes and were validated in HWW, while four MTAs represent likely novel loci for FHB resistance. Accumulation of favorable alleles of reported MTAs resulted in significantly lower mean DIS and FDK scores, demonstrating the additive effect of FHB resistance alleles.

Application/Use:

Breeding efforts with time will result in the enhancement of FHB resistance and good straw strength in winter wheat germplasm. The improved lines will be recommended for release as varieties for production in the region. The improved germplasm will form the foundation of the next breeding cycle and will also be shared with breeding programs in the region.

Entry	FHB Index	Yield (bu/ac)	TW (lb/bu)	Protein (%)	Heading	Height (inches)	Lodging (0-9)
REDFIELD	19.7	55.2	57.1	14.9	161.0	31.1	2.0
SD19B089-3	19.7	54.8	57.5	14.3	159.9	33.3	2.4
EXPEDITION	22.0	54.3	58.0	14.8	156.6	32.2	3.5
WINNER	22.6	54.1	57.8	14.5	158.5	31.1	1.8
SD18B055-2	23.2	56.8	57.9	14.1	159.2	31.6	1.9
SD18D037-11	23.5	56.4	58.5	14.4	159.3	33.0	2.8
SD19B011-2	25.6	52.4	57.9	15.1	158.5	32.5	2.4
SD19B057-1	25.8	54.0	57.9	15.1	158.2	32.8	2.1
SD19B051-3	26.7	54.1	57.3	15.1	161.3	31.5	2.2
SD18B016-5	27.0	56.1	58.1	14.3	159.7	32.1	2.2
SD19B016-1	27.3	52.3	57.7	15.2	159.0	33.0	2.5
SD19B002-1	27.8	53.7	57.3	14.7	161.8	31.4	2.6
SD19B136-3	28.0	55.4	58.5	14.6	159.3	33.3	2.5
SD19B087-1	28.1	53.4	57.2	14.5	160.4	31.4	1.8
OVERLAND	29.3	57.7	58.4	14.3	159.6	33.5	2.6
SD18D074-11	29.7	53.7	57.5	14.6	162.4	33.6	2.3
SD19B153-2	30.0	54.1	58.0	14.6	161.3	32.4	2.5
SD19B176-2	30.0	55.8	58.0	14.7	160.6	31.3	1.9
SD19B004-1	30.3	55.5	58.0	14.6	158.7	31.9	2.0
SD19B108-3	30.3	56.6	58.0	14.2	159.2	32.3	2.3
SD18B061-4	30.3	54.2	58.3	15.2	161.0	32.2	1.7
SD18D042-3	30.5	52.2	57.2	14.4	161.3	32.3	2.9
SD19C008-3	30.9	53.8	58.5	14.3	159.3	34.1	2.7
SD18D080-2	31.7	56.0	58.3	14.5	159.8	33.4	2.9
KELDIN	31.9	56.2	57.9	14.5	162.7	31.7	1.6
SD18D035-6	32.9	51.7	57.2	15.0	159.1	31.4	2.4
SD19B183-1	33.4	54.8	57.9	15.0	159.9	32.1	2.4
SD19D133-4	33.4	54.5	57.1	14.8	158.4	32.7	3.1
SD19B024-2	33.5	57.8	57.4	14.2	159.9	34.1	3.4
SD18B062-12	33.6	53.7	57.1	14.8	161.5	33.0	2.2
SD18D043-5	36.2	54.2	54.9	14.7	160.6	33.5	4.2
SD19B162-1	38.0	53.1	56.7	14.7	161.5	33.3	2.3
SD19B164-3	40.6	56.7	56.3	14.5	159.7	31.8	1.9
SYMONUMENT	45.6	55.7	56.2	14.1	161.3	31.3	2.1
SD19B020-2	47.7	53.3	57.8	15.2	161.3	33.9	1.8
SD19B104-2	50.9	53.6	56.1	14.9	160.8	30.9	2.4
Grand Mean	31.2	54.7	57.5	14.6	160.1	32.4	2.4
LSD	5.7	2.7	0.9	0.3	0.8	0.9	0.7
CV	23.0	8.1	3.3	3.7	0.6	4.6	32.2

Table 1. South Dakota State University hard winter wheat Elite yield trial (Elite) entries ranked according to FHB disease index values (lowest to highest – collected at Volga farm) presented along with agronomic data obtained from three replication trials conducted at nine test environments in 2022. The heading data is days to on Julian calendar and Lodging was rated at harvest on a scale of 0-9; 0- no lodging and 9- complete lodging.

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Materials and Methods:
Each year we make several hundred crosses in hard winter wheat (HWW) and about 40 crosses/backcrosses in soft white winter wheat (SWW) market class. The crosses are developed for agronomic traits (grain yield, test weight, protein content, straw strength, etc), end-use quality traits, and resistance to diseases and insect pests. However, the main goal of this project is to enhance the straw strength and FHB resistance in winter wheat along with winter hardiness to develop varieties adapted to this region. The major sources of FHB resistance are native (Lyman, Everest Overland, and Emerson), Fhb1 and Fhb6 and for increasing straw strength, the focus is on semidwarf genotypes carrying Rht1b. The F1's are backcrossed or seed increased in the greenhouse and then 500 F2 plants are screened for with molecular markers (Fhb1/Fhb6) in target crosses and the selected F2 plants are advanced to the next generation as mini-bulks through speed breeding (Fig. 1) or in the field to F4 generations. The F4 population is space planted to select plants with shorter height and tillering capacity and early maturity. The selected plants are planted in short 5 ft 4-row early observation trial (EOT). The EOT entries are screened for FHB markers (for confirmation) and selected based on winter hardiness, resistance to other diseases (rust and Bacterial Leaf Streak), and agronomic traits like plant height, maturity, yield, test weight, and grain protein. The best performing breeding lines from EOT are advanced to preliminary (three locations) then to advanced yield trials (AYT) at 3 (SWW-AYT) and 7 (HWW-AYT) locations and finally, the hard winter wheat lines are advanced to elite yield trials (Elite) at 8 locations. Currently, we are evaluating 20 SWW lines in our SWW-AYT, 126 HWW in our HWW- AYT, and 36 HWW lines in our HWW-Elite trials. The AYT and Elite lines are evaluated for FHB resistance in our mist-irrigated FHB field nursery. Further, all quality parameters of the advanced and Elite lines are evaluated. GS approaches are also being evaluated in the breeding program for various traits. The 2-3 lines showing superior performance in AYT, and Elite trials are submitted to the Minnesota State Variety trials conducted by (Dr. Jared J. Goplen and Dr. Jochum J. Wiersma) at 5 locations in MN.

Economic Benefit to a Typical 500 Acre Wheat Enterprise:
The development of winter wheat varieties adapted to Minnesota and the region can bring significant benefit to the regional producers in terms of revenue as winter wheat varieties would typically yield ~10 % more than spring wheat due to the longer growing season. This would account for additional 5 bu per acre. In addition, winter wheat on a farm would spread the producer's workload as it is planted in the fall and helps compete with weeds in a corn-soybean rotation. The fall-planted winter wheat keeps the ground covered preventing soil erosion and captures fall moisture and provides an opportunity to include cover crops in rotation. Lastly, studies have shown having wheat in crop rotation enhances yield in the following corn crop by nearly 10%.

Related Research:
These funds provide general support for our breeding program to develop winter wheat varieties adapted to the region and provide value addition to the producer and meet the needs of the local milling industry. Additional funding for breeding activities comes from South Dakota Wheat Commission and U.S. Wheat and Barley Scab Initiative via USDA-ARS.

Publications:
Zhang J, Gill HS, Halder J, Brar NK, Ali S, Bernardo A, Amand PS, Bai G, Turnipseed B, Sehgal SK (2022) Multi-locus genome-wide association studies to characterize Fusarium head blight (FHB) resistance in hard winter wheat. Front Plant Sci 13: 946700. https://doi.org/10.3389/fpls.2022.946700

Zhang J, Gill HS, Brar NK, Halder J, Ali S, Liu X, Bernardo A, Amand PS, Bai G, Gill US, Turnipseed B, Sehgal SK (2022) Genomic prediction of Fusarium head blight resistance in early stages using advanced breeding lines in hard winter wheat. The Crop J (Early version). https://doi.org/10.1016/j.cj.2022.03.010 [IF: 4.64]

Bacterial seed inoculation to improve nitrogen uptake and use efficiency in wheat

Paulo Pagliari and Lindsay Pease

Project Period: 01/01/2022 to 12/31/2022

Research Question/Objectives:
Determine if inoculation of wheat with plant growth promoting bacteria has a positive impact on wheat growth and yield.

Measure soil available nitrogen after inoculation with plant growth promoting bacteria.

Assess nitrogen uptake in plots inoculated with plant growth promoting bacteria

Results:
The 2022 growing season was very atypical with very limited rainfall during critical grain filling stages. In general wheat yield at Crookston was 75 bu/ac for wheat following corn (Figures 1, 2, 5 and 6) and 49 bu/ac for wheat following soybeans (Figures 3, 4, 7 and 8). At Lamberton wheat yield was 68 and 47 bu/ac for wheat following corn (Figures 1, 2, 5 and 6) and soybeans (Figures 3, 4, 7 and 8), respectively. Statistical analysis showed that there were no significant treatment effects at either location. Not even a response to N rates was observed for wheat yield (Figures 1, 2, 3, 4). This result is very unexpected as a N response is almost always observed under similar conditions. Lack of rainfall during grain filling stages could have limited the wheat ability to produce high yield this year.

The effect of inoculation could not be determined either as no significant differences were observed for inoculation rate, although there were two trends worth of mentioning. Figure 5 shows that at Crookston inoculation with 0.69oz and applying 45 lbs N/ac resulted in 26 bu/ac more than 0 N treatment. In contrast, Figure 6 shows that at Lamberton inoculation with 0.69oz and 0 N/ac resulted in 12 bu/ac more than the 45 lbs N/ac treatment. Both of these significant differences were observed for wheat after corn. Most of the positive responses for Azospirillum inoculation in our first trial in 2021 were also observed for wheat following corn.

The soil samples and grain samples collected during the growing are now being processed and analyzed for soil available N and grain N uptake. The final report will contain the statistical analysis and results from these chemical tests.

In conclusion the second year for this was also challenging and inconclusive results were observed. Azospirillum is in many cases inoculated alongside other beneficial bacteria such as Pseudomonas, Bacillus, and others. It is possible that a different mix could help improve wheat tolerance to limited available water during critical grain filling periods. Climate change is likely to accentuate how serious this problem is as rain patterns shift even more in response to unpredictable global changes.

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Figure 1. Wheat grain yield for inoculated and non-inoculated wheat following corn under different N application rates at Crookston

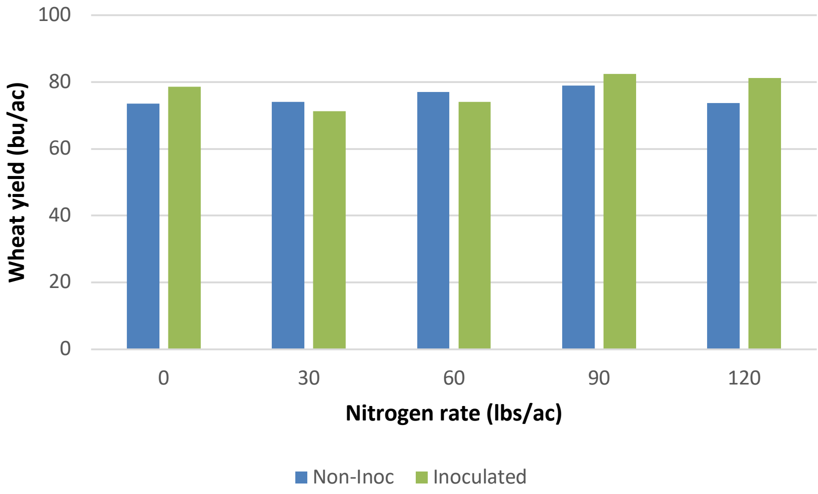

Figure 2. Wheat grain yield for inoculated and non-inoculated wheat following corn under different N application rates at Lamberton

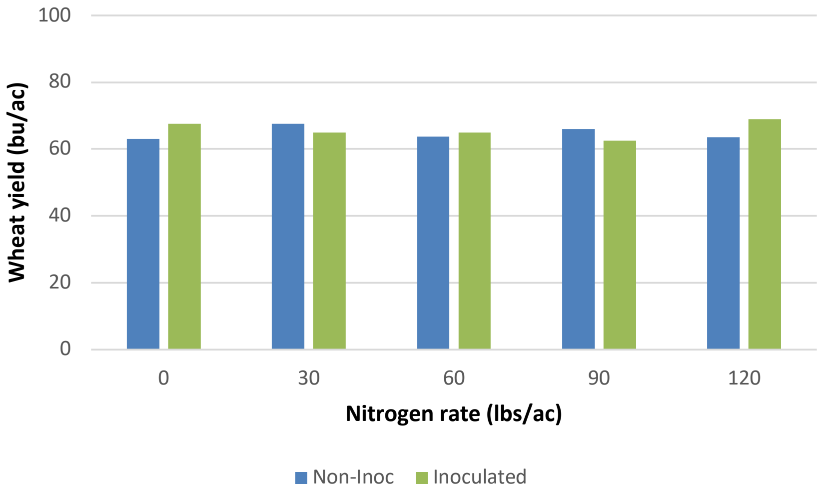

Figure 3. Wheat grain yield for inoculated and non-inoculated wheat following soybean under different N application rates at Crookston

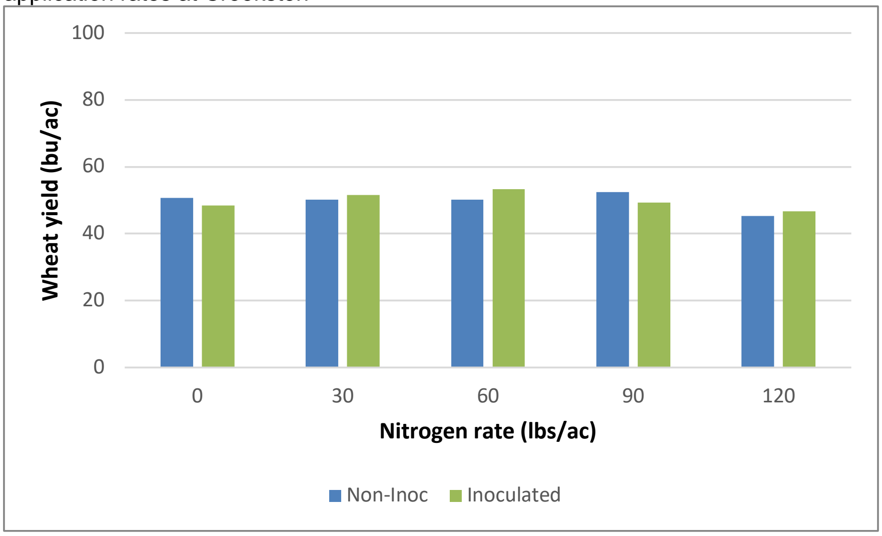

Figure 4. Wheat grain yield for inoculated and non-inoculated wheat following soybean under different N application rates at Lamberton

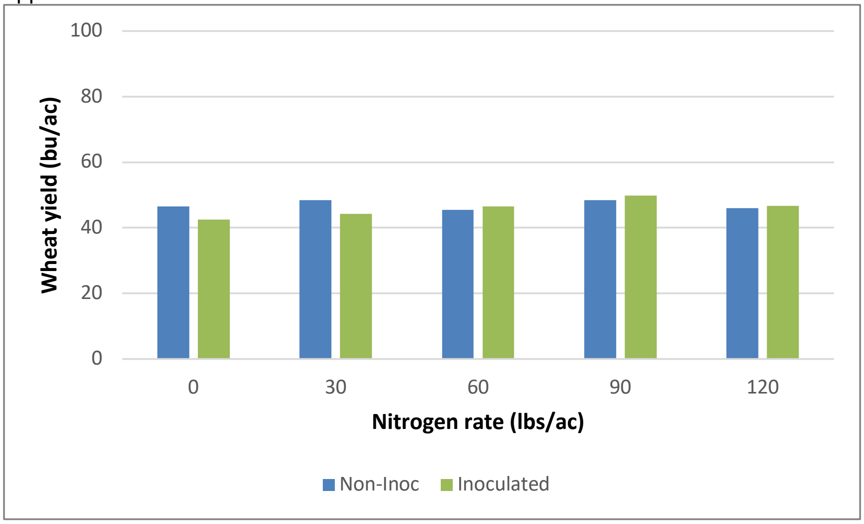

Figure 5. Wheat grain yield receiving 0 or 45 lbs N/ac following corn under different inoculation rates at Crookston. (Stars indicates a significant difference)

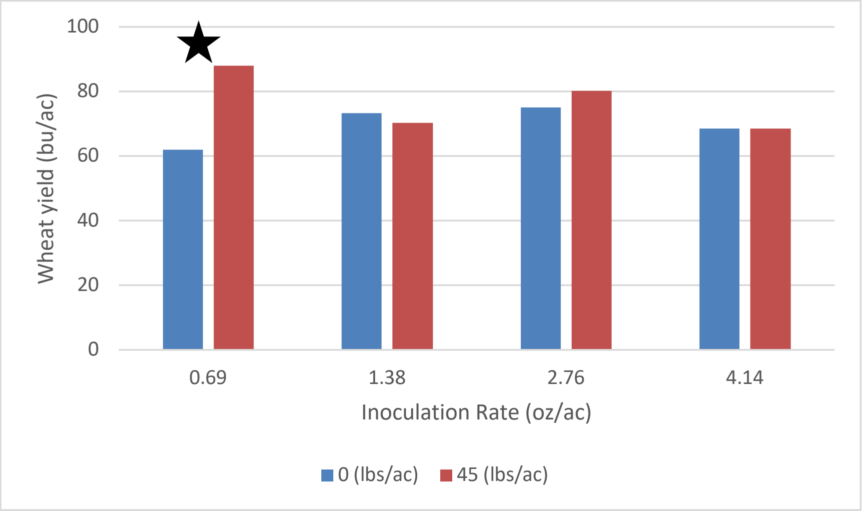

Figure 6. Wheat grain yield receiving 0 or 45 lbs N/ac following corn under different inoculation rates at Lamberton. (Stars indicates a significant difference)

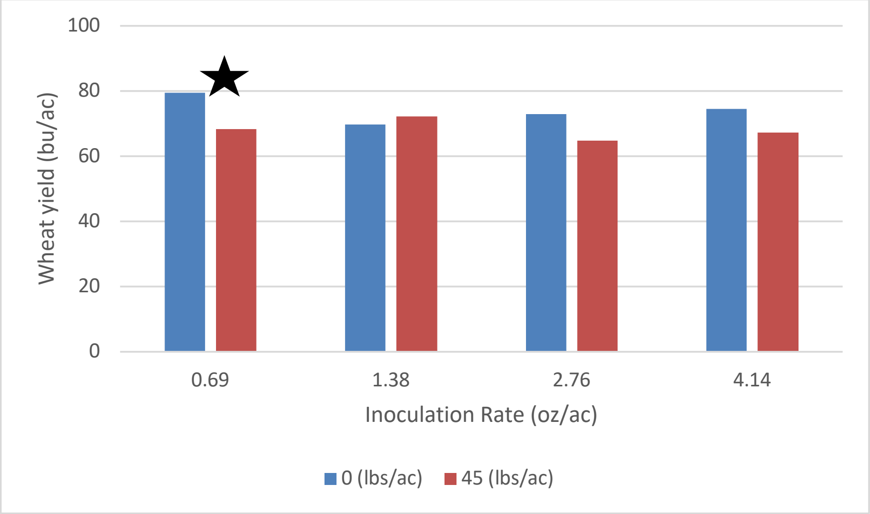

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Figure 7. Wheat grain yield receiving 0 or 45 lbs N/ac following soybean under different inoculation rates at Crookston.

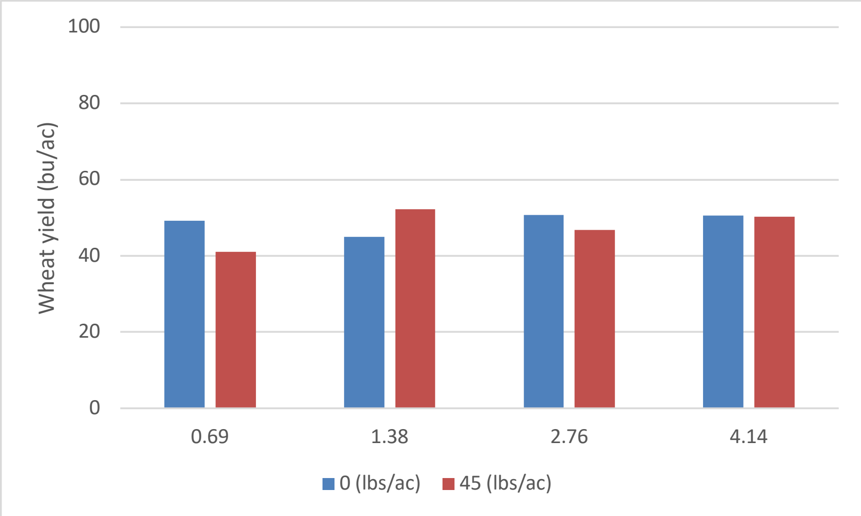
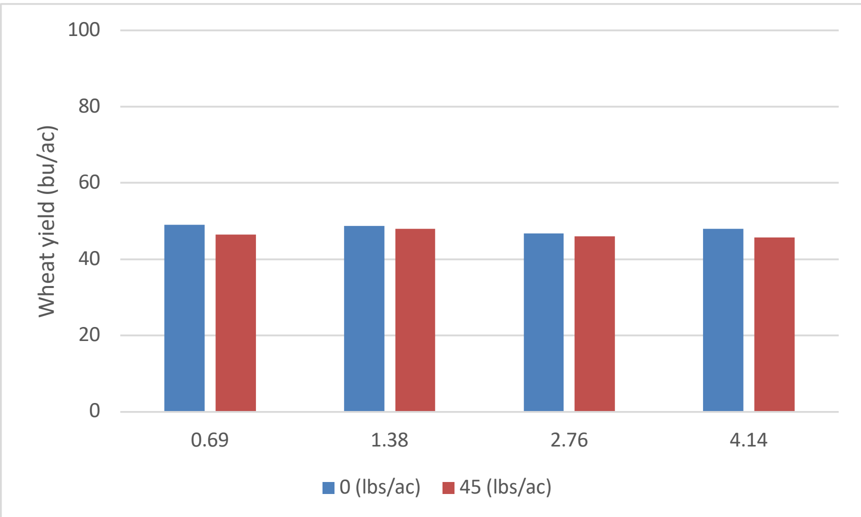


Figure 8. Wheat grain yield receiving 0 or 45 lbs N/ac following soybean under different inoculation rates at Lamberton.



Application/Use:

Our main goal with this project is to improve nitrogen fertilizer use and help wheat growers be more profitable. Nitrogen fixing bacteria can remove N from the atmosphere and convert it into ammonium or nitrate in the soil which is available for plant uptake. Finding management practices that reduces the cost of production to farmers could lead to significant savings improving overall profits.

Materials and Methods:

Replicated field studies were conducted at two of the University of Minnesota research and outreach center at Lamberton (SWROC) and Crookston (NWROC). To test the effects of seed inoculation on wheat grain yield, wheat was planted after soybean and corn, at Lamberton and Crookston. Treatments tested were inoculation and nitrogen rates. For the inoculation rate portion of the study a fixed N rate was used (45 lbs N ac-1) and the levels of inoculation were 0x, 0.5x, 1x, 2x, and 3x, with x being the recommended inoculation rate (0,69 oz of inoculum per acre). For the N rate portion of the study, there were plots which were inoculated at the 1x inoculum rate and also plots which were not inoculated; nitrogen rates were 0, 30, 60, 90, and 120 lbs of N / acre. Each study was replicated four times for a total of 100 plots in each location. Having equivalent N rates with and without inoculation could allow us to determine the true potential for N fixation from the seed treatments and if a reduction in N fertilization is possible with this seed treatment. Wheat was harvested using plot combine and wheat grain samples were saved for N uptake analysis which is currently being performed at Lamberton in Dr. Pagliari labs.

Economic Benefit to a Typical 500 Acre Wheat Enterprise:
The benefit to wheat growers would be increased wheat yield with lower N application rates. By reducing the amount of N needed for maximum wheat yield growers would save on fertilizers, specially when fertilizer prices are as high as they are going to be in the 2023 growing season. In addition, lower amounts of N applied to cropping fields will also reduce the amount of N that can potentially cause environmental problems to aquatic systems and drinking water.

Related Research:
Nitrogen (N) fertilization is one of the highest costs in the production process of non-leguminous crops such as wheat (Triticum aestivum). Developing management practices which minimize the reliance on chemical N inputs are critical for global food security and environmental sustainability. Recent research has shown the potential for utilization of plant growth promoting bacteria (PGPB) to enhance nutrient use efficiency in non-leguminous cropping systems (Galindo et al., 2021a). This has the potential to reduce both costs associated with fertilizer purchases and N loss to the environment. Microorganisms such as Azospirillum brasilense and Bacillus subtilis, are PGPB known to have a significant effect on the nutrient balance in the soil-plant ecosystem. The mutualism relationship between PGPB, soil microflora, and plants could lead to better plant nutrition and development and increased productivity, while minimizing the needs for external inputs. The PGPB are nonpathogenic residents of plants or/and soil who act directly to promote growth or indirectly as biological control agents of plant diseases (Mariano et al., 2004). The use of inoculation in non-leguminous crops with non-symbiotic PGPB is increasing in Latin America, in particular for wheat and corn crops (Marks et al., 2015; Salvo et al., 2018; Galindo et al., 2021b). The use of PGPB can significantly reduce the amount of chemical N needed for optimum wheat productivity (Galindo et al., 2021a,b). Therefore, the overall hypothesis of this study is that A. brasilense and B. subtilis could promote plant growth by increasing biological N fixation (BNF), N use efficiency, overall nutrient uptake, and reduce biotic and abiotic stress.

Recommended Future Research:
This was the second trial conducted in the USA using this specific Azospirillum strain. 2021 was a very challenging growing season and water stress limited plant yield, and the weather conditions in 2022 were similar to those in 2021. Future research needs to be conducted to assess the true potential for the use of this organism at supplying wheat with N from atmospheric N gas under different weather conditions.

References:
Galindo, F.S., Pagliari, P.H., Buzetti, S., Rodrigues, W.L., Fernandes, G.C., Biagini, A.L.C., Tavanti, R.F.R. and Teixeira Filho, M.C.M., 2021a. Nutrient availability affected by silicate and Azospirillum brasilense application in corn–wheat rotation. Agronomy Journal.
Galindo, F.S., da Silva, E.C., Pagliari, P.H., Fernandes, G.C., Rodrigues, W.L., Biagini, A.L.C., Baratella, E.B., da Silva Junior, C.A., Neto, M.J.M., Silva, V.M. and Muraoka, T., 2021b. Nitrogen recovery from fertilizer and use efficiency response to Bradyrhizobium sp. and Azospirillum brasilense combined with N rates in cowpea-wheat crop sequence. Applied Soil Ecology, 157, p.103764.
Mariano RLR, Silveira EB, Assis SMP, Gomes AMA, Nascimento ARP, Donato VMTS. 2004. Importance of plant growth-promoting rhizobacteria for a sustainable agriculture. (In Portuguese, with English abstract). Anais Acad. Pernamb. Ci. Agron. 1:89-111.
Marks BB, Megías M, Ollero FJ, Nogueira MA, Araujo RS, Hungria M. 2015. Maize growth promotion by inoculation with Azospirillum brasilense and metabolites of Rhizobium tropici enriched on lipo-chitooligosaccharides (LCOs). Amb Express 5:71-82. doi: 10.1186/s13568-015-0154-z.
Salvo LP, Ferrando L, Fernandéz-Scavino A, Salamone IEG. 2018. Microorganisms reveal what plants do not: wheat growth and rhizosphere microbial communities after Azospirillum brasilense inoculation and nitrogen fertilization under field conditions. Plant Soil 424:405-417. doi: 10.1007/s11104-017-3548-7.

Research on Bacterial Leaf Streak of Wheat

Ruth Dill-Macky

Project Period: January 1, 2022 – December 31, 2022

Research Question/Objectives:
This project continues our efforts to address the control of bacterial leaf streak (BLS) of wheat. The ultimate goal of the project was to deliver economic disease control measures to growers. We conducted research to examine the biology of the BLS pathogen with the aim of uncovering avenues of disease control that compliment host resistance. Outcomes of practical value to the wheat grower include understanding the role that seed plays in the survival of the pathogen, the validation of tools to identify the bacterium that incites BLS within seed, crop debris and in soil samples, along with the testing of treatments to disinfest seed. Our previous research indicated that infested seed poses a risk to the subsequent crop, and we have tested protocols to quantify bacteria in seed. We proposed to adapt this test in 2022 to other matrices (crop residues and soil) and to test a protocol that should differentiate between living and dead bacterial cells. We also examined the efficacy of seed treatments in disinfesting seed that is contaminated with the pathogen and evaluated a number of foliar treatments, both chemical and biological, for the control of BLS in the field.

Results:
Validate molecular assays as tools to rapidly and reliably identify Xtu in plant tissues and soil samples.

- The LAMP assay described by Langlois et al. (2017) and a multiplex PCR described by Roman-Reyna et al. (2022) have been validated using both seed and plant tissue.
- A qPCR protocol developed by Hong et al. (2023, in press) has also been validated using pure X. translucens pv. undulosa cultures.
- We have preserved bacterial suspensions from artificially inoculated seed and leaf tissue from both the field and the growth chamber experiments to validate the qPCR method using these tissue types.
- We will also test naturally infected seed exhibiting black chaff symptoms from the 2022 MN-on farm variety trials.
- Development and optimization of a viability qPCR protocol that will detect and quantify viable X. translucens cells is ongoing.

Determine where in the wheat seed the bacterium is surviving

- A previous preliminary experiment to develop a method to artificially inoculate seed heads in the greenhouse was unsuccessful. This would have allowed us to visualize strains tagged with a fluorescens protein using microscopy.
- Our approach pivoted to examine seed that has been dissected into bran and endosperm and use the qPCR assay to quantify the bacterial load in each fraction. This work is ongoing, and we plan to use seed from the On Farm Variety Trials, as well as seed harvested from plants artificially inoculated in field plots in 2022. This seed is currently being processed.

Determine how long the bacterium is surviving in association with wheat seed.

- Once the viability qPCR is optimized, infested seed harvested in 2022 will be tested to quantify viable bacterial cells at weekly intervals to determine the longevity of the bacterium. The seed for this experiment is still being processed.

Examine the efficacy of seed treatments in reducing Xtu in association with seed.

- A previous preliminary experiment applying dry heat of 72 °C for 4 days as recommended by Fourest et al. (1990) killed the bacteria, but also killed the seed embryo resulting in 0% germination. We are going to use the seed from 2022 that is currently being processed to test a more expansive temperature and time range to evaluate dry heat treatments. Similarly, we will examine the efficacy of a wet heat treatment by placing infested seed in a hot water bath. We can utilize the viability qPCR to quantify living bacteria after heat treatments.

Conduct field trials in collaboration to examine the efficacy of commercial foliar treatments on BLS.

- Two field experiments were conducted, one in Crookston and one in St. Paul. The treatments examined included:
- MasterCop (copper sulfate pentahydrate): applied at early heading (16 fl oz/A) and 10 days later (8 fl oz/A)

- Aviv (biological/Bacillus): applied at early heading (25 fl oz/A) and 10 days later (25 fl oz/A)
- SaniDate 5.0 (hydrogen peroxide): applied at early heading (13.6 fl oz/A) and 10 days later (13.6 fl oz/A)
- Kocide 3000-O (copper hydroxide): applied at early heading (0.75 lb/A) and 10 days later (0.75 lb/A)
- Champ WG (copper hydroxide): applied at early heading (1 lb/A) and 10 days later (1 lb/A)
- Aviv (biological/Bacillus): applied at 4-5 leaf (25 fl oz/A) and 10 days later (25 fl oz/A)
- SaniDate 5.0 (hydrogen peroxide): applied at 4-5 leaf (13.6 fl oz/A) and 10 days later (13.6 fl oz/A)
- Two untreated controls were included – one was not inoculated with the BLS pathogen and the other was inoculated. All the plots treated with a product were inoculated with the pathogen

Plots were rated for visual disease development (Table 1) weekly after symptoms appeared till the plots began to mature, the plots were harvested at maturity and yield and grain weight was examined.

- None of the treatments tested reduced the symptoms of BLS and none reduced yield. The only treatment that could be distinguished was the non-inoculated treatment, where plots yielded 20% more than the all the other treatments and where few BLS symptoms were evident.

In addition to these objectives, we evaluated the ability of X. translucens to be transmitted into growing plant tissue from artificially inoculated seed by vacuum infiltration in a sterile environment and the field. Wheat and barley seed was inoculated using rifampicin resistant strains of X. translucens pv. undulosa (Xtu) and X. translucens pv. translucens (Xtt), respectively. Seeds were placed in sterile culture boxes containing water agar and placed in a growth chamber. The coleoptile, 1st and 2nd leaves were sampled and extracts were plated onto Wilbrink's media supplemented with rifampicin, so that only the rifampicin resistant strains used to inoculate would be recovered. Both Xtu and Xtt were recovered from their respective host at all growth stages sampled. Field trials were conducted in two sites on the St. Paul campus, one dryland and one irrigated site. Seed was inoculated in the same manner and with the same strains as in the growth chamber experiments. Plants were sampled weekly beginning with the 3rd leaf through soft dough. Extensive bird damage occurred on maturing seed. Under dryland conditions only Xtt on barley was recovered from 3rd leaf through 6th leaf stages on most replications. Xtt was not recovered from flag leaves or soft dough spikelets. Xtu was recovered only from one replication at the 5th and 6th leaf stage, and not recovered at any other growth stage. Under irrigated conditions both Xtu and Xtt were recovered at all growth stages sampled from wheat and barley, respectively.

- This work indicated that moisture likely plays a role in seed transmission and movement up the plant, particularly in the case of Xtu on wheat.

Application/Use:
Bacterial leaf streak (BLS) of wheat, caused by Xanthomonas translucens pv. undulosa (Xtu), is presently the most important foliar disease of wheat in Minnesota. Managing BLS is difficult, as fungicides are largely ineffective against bacterial pathogens. Previous work, funded by the MWRPC, has enabled us to establish a regional screening nursery for BLS providing data for growers of the relative resistances in commercial wheat varieties. Although host resistance is critical to disease control, there is no immunity to BLS and additional control options would be advantageous to growers. This project proposed research aimed at developing additional tools that can be used by the grower in the management of BLS. In conjunction with the use of varieties with improved resistance, these tools can provide additional options to the grower in the management of this economically important disease.

Materials and Methods:
1. Validate molecular assays as tools to rapidly and reliably identify Xtu in plant tissues and soil samples.
In 2021 we tested molecular assays (LAMP and PCR) to identify Xtu in wheat seeds. These assays have several practical applications, including identifying seed lots that are free of, or minimally infested with, Xtu. Our goal was to be able to effectively detect contaminated seed lots, such as samples submitted by growers to the UMN Plant Disease Clinic or seed that the breeding programs ship internationally. Clean seed may prove an effective way to reduce the risk of disease in high value seed lots, including foundation seed and seed exchanged between countries such as the UMN breeding program's winter increase in New Zealand. In the 2022 project we worked to validate the molecular tools (LAMP and PCR assays), developed to identify Xtu-contaminated seed lots, and to detect the pathogen in other matrices including plant tissues and soil. The two assays (LAMP and PCR) are based on the detection of DNA.

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We did this work to determine where the bacterium is surviving between growing seasons, and crop debris and soil had yet to be studied as potential pathogen reservoirs. The ability to detect the pathogen is key to elucidating its full lifecycle and identifying where it survives between growing seasons may suggest additional control options. We also worked to adapt a qPCR protocol that detects and quantifies viable X. translucens cells. Such a method has been developed for the related bacterium, Xanthomonas hortorum. We are using seed from the 2022 field season Minnesota on-farm variety trials to validate the detection of Xtu in seed using the methods outlined above. Jochum Wiersma (UMN), alerted us to those locations with significant naturally occurring BLS. We traveled to these sites, rated BLS and obtain seed following harvest from select varieties (including both BLS susceptible and BLS resistant varieties) from locations with high and low disease pressure. In addition to validating the best of the three molecular tests (LAMP, PCR and/or qPCR) available, we also isolated bacteria from these samples using dilution plating to confirm the presence of viable bacterial cells in the test samples.

2. Determine where in the wheat seed the bacterium is surviving. We continue the work started in 2020 in 2022 to examine how Xtu colonizes wheat seed to determine where in the wheat seed the pathogen is residing. If Xtu lacks the ability to enter the interior of the seed, antibacterial seed treatments, such as copper compounds, or physical seed treatments such as the applications of heat, may prove useful in reducing seed transmission of the pathogen. Seed will be dissected into major components (bran and endosperm) and qPCR will be used to quantify the bacterial load in each component. This work should confirm if Xtu is inside the wheat seed and associated with the embryo, or if Xtu is surviving only on the seed coat. This work is still to be completed over the coming weeks.

3. Determine how long the bacterium is surviving in association with wheat seed. In addition to understanding where in the seed Xtu is surviving, we plan to use the qPCR assay to quantify bacterial cells in seed obtained from the on-farm yield trials, and/or following artificial inoculation, at regular intervals after harvest to determine how long the bacteria associated with seed remain viable. An understanding of the duration of viability would also aid in developing recommendations for seed handling and treatments aimed at reducing the risk of BLS in a subsequent crop.

4. Examine the efficacy of seed treatments in reducing Xtu in association with seed. Physical treatments, such as heat (wet or dry), are reported to be effective in killing the bacteria in association with seed. In 2020 we started to examine the role of infected seed in the epidemiology of BLS. In 2022 we examined the use of wet and dry seed treatments on naturally infected seed, obtained from the Minnesota on-farm variety trials, with the goal of reducing Xtu in association with seed. However, physical seed treatments, like chemical treatments, are associated with decreased seed germination and are also most effective on bacteria located close to the seed surface. Seed treatments appear to be most effective when combined with a rapid and reliable test that determines the level of infestation and will likely be limited to use in high value seed lots. Recovery of the bacterium, using dilution plating before and after treatment, was used to determine the efficacy of the treatments. Germination tests were also conducted to determine the impact of the treatments on seed viability.

5. Conduct field trials in collaboration to examine the efficacy of commercial foliar treatments on BLS. We undertook field trials at two Minnesota(St Paul and Crookston) to examine several commercially available copper-based (Champ WG, Kocide 3000-O, SaniDate 5.0, and MasterCop) and one biological treatments (Aviv [Bacillus]) on BLS development in wheat. In addition, non-inoculated and inoculated & untreated control treatments will be included. The trials were inoculated, and BLS development was assessed visually weekly for five weeks following the first observations of symptom development. Yield and test weights were determined at harvest. Our first year of testing, conducted in 2021, showed little impact of copper-based treatments however the dry season was generally unfavorable for BLS development and in 2022 we expanded the number of compounds we are examining.

Economic Benefit to a Typical 500 Acre Wheat Enterprise

We have demonstrated that bacterial leaf streak (BLS) is of economic importance to the wheat industry. Our data on the response of varieties would allow a grower to select wheat varieties for production that are less susceptible to BLS. The development and introgression of host resistance provides economic and environmentally sustainable control of wheat diseases. Our most recent work has demonstrated the role that seed plays in the survival of the pathogen, provided tools to identify the bacterium that incites BLS within seed, crop debris and in soil samples, along with the testing of treatments to disinfest seed. We have evidence that copper-based products do not provide any reduction in BLS.

Related Research:
We have established close relationships with research and extension plant pathologists and the wheat breeding programs (public and private) in Minnesota and in neighboring states.

Publications:

Curland, R.D., Hallada K.R., Ledman, K.E., and Dill-Macky, R. (2021). First report of bacterial leaf streak caused by Xanthomonas translucens pv. undulosa on cultivated wild rice (Zizania palustris) in Minnesota. Plant Disease, 105:2771.

Ledman, K.E., Curland, R.C., Ishimaru, C.A., and Dill-Macky, R. (2021). Xanthomonas translucens pv. undulosa identified on common weedy grasses in naturally infected wheat fields in Minnesota. Phytopathology, 111:1114-1121.

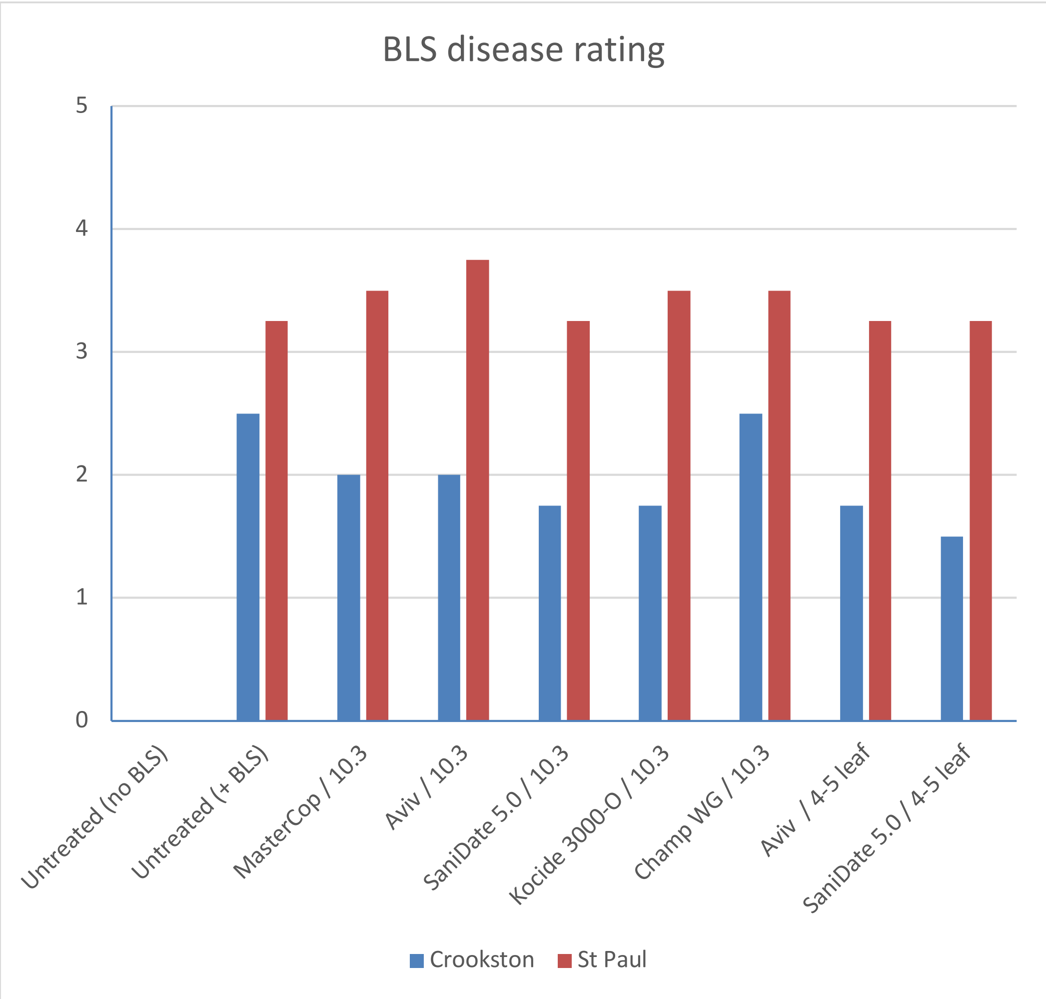

Table 1: BLS symptoms on a 0-9 scale observed 14 days after the initial development of symptoms in field trials conducted at Crookston and St Paul to examine the efficacy of copper-based bactericides (MasterCop, Kocide-3000, and Champ WG), hydrogen peroxide (Sanidate 5.0) and a biological (Aviv) in reducing BLS development. All plots were inoculated with the BLS pathogen, except the non-inoculated control where little disease developed at either location. All treatments were applied twice, with the first application at either the 4-5 leaf stage or at early anthesis. In each case the second application was applied 10 days after the first with the maximum rate provided on the label applied over the two applications. No product appeared effective in reducing disease development or preventing yield losses.

Southern Minnesota Small Grains Research and Outreach Project

Dr. Jochum J. Wiersma

Project Period: 01/01/2022 – 12/31/2022

Research Question/Objectives:
The objectives of this grant were to:
- Evaluate variety performance for Hard Red Spring Wheat (HRSW) and Hard Red Winter Wheat (HRWW) varieties across southern Minnesota with locations at Becker, Benson, LeCenter, and Rochester.
- Organize extension programming for small grain production and management in southern Minnesota using summer field days and winter meetings.

Results:
The winter extension programming for small grains production and management in central and southern Minnesota were held in Morris, New Prague, Rochester, Slayton, and Benson in 2022. Each workshop had a regional focus. Attendance totaled about 100 people across these five locations or about half of the attendance prior to the COVID-19 pandemic. The meetings were well received, with 100% of attendees responding that they would recommend the program to others. All of the workshop attendees also reported having a deeper understanding of the subject matter as a result of attending the sessions, while 89% of attendees planned to change production practices due to attending a workshop. Field days were held from June 27th near Le Center and New Ulm to showcase variety trials. Attendance totaled 30, again about half of the attendance prior to the COVID-19 pandemic. No field day was organized near Benson nor is data reported from the trial because the trial was lost due to early season flooding.

A summary of the attained grain yield of the HRSW and HRWW variety trial results can be found in tables 1 and 2. The average yield across the two southern Minnesota locations from data was reported at the time of writing was 69 bu/ac for HRWW (2 locations) and 58 bu/ac for HRSW (6 locations). Plots were also used as sentinel plots to monitor disease and insect pests during the growing season (In conjunction with the Minnesota Small Grains Pest Survey).

Application/Use:
Central and southern Minnesota have not had large small grain acreages in recent decades. Small grains have often been grown in this region for reasons other than maximized production, such as manure applications, straw production, forage/cover-crop establishment, or tiling projects. The combination of weed and insect resistance issues, and interest in diversifying crop rotations to improve soil health has inspired more farmers in these regions to consider growing small grains. Our research and demonstration plots have documented the ability to grow small grains in central and southern Minnesota with high yield and quality that can maximize profitability. Our results have been echoed by reports from farmers in these regions who utilize advanced management tools and genetics despite the added production risks of heat and disease stressors that are more prevalent in southern Minnesota.

Materials and Methods:
The winter wheat and rye variety trials had 32 and 16 entries, respectively. The spring wheat, oats, and barley variety trials had 66, 30, and 22 entries, respectively. Trials were all a randomized complete block design with either three or four replications. Field preparations and fertility management were completed by plot cooperators and represented typical production practices. Planting, weed control, data collection, and harvest were completed by the research group.

Economic Benefit to a Typical 500 Acre Wheat Enterprise:
Variety selection is one of the most critical decisions made on a wheat enterprise. A well-adapted versus a poorly-adapted variety can be the difference in farm profitability. Even with a very late start across Minnesota, there was a 14 bu/ac difference between the highest-yielding 10% of varieties and the lowest-yielding 10% of varieties in the HRSW variety trials across the six southern Minnesota location. This 14 bu/ac difference in yield could increase returns by over $120 per acre, or over $ 60,000 in gross returns for a 500-acre wheat enterprise. All while only changing variety selection. Variety trials are especially valuable in southern Minnesota, where variety trial information is otherwise limited. The ability to recommend varieties adapted to southern Minnesota as well as for farmers

to see varieties firsthand before planting them has an invaluable impact on current and future wheat farmers in southern Minnesota. These trials also influence the spring wheat, barley, and oat breeding programs at the University of Minnesota, by allowing on-farm assessments of yield, disease, lodging and other agronomic characteristics that are used to influence future varietal releases and agronomic ratings. These factors further add to the long-term impact that this project has on a typical wheat farm in Minnesota.

Related Research:
This research is integrally linked with the small grain breeding programs at the University of Minnesota. The spring wheat, barley, and oat breeding programs utilize the data generated in these trials as part of their southern small grain variety performance evaluations, which expands the geographical coverage of small grain variety trials as well as provides on-farm credibility to the variety evaluations. The rye variety trials also link with this project with funding from other sources.

Recommended Future Research:
Variety trial data is much more valuable when it is aggregated with ongoing variety trials. Just because a variety performed well one year does not mean it will repeat the same in the future. Variety selections should be based on multiple years of data from multiple locations. This is why these variety trials should be continued into the future so that farmers can continue to refine their variety selections as new genetics become available.

Publications:
Results of yield trials for spring and winter wheat, barley, oats, and winter rye are part of the variety trial results that will be published in the on-line publication Minnesota Field Crop Variety Trials (https://varietytrials.umn.edu/). The 2021 trial results were published in:

- Anderson J.A, J.J. Wiersma, S. Reynolds, N. Stuart, H. Lindell, R. Dill-Macky, J. Kolmer, M. Rouse, and Y. Jin. 2021. Hard Red Spring Wheat. In: 2021 Minnesota Field Crop Variety Trials. Minnesota Agricultural Experiment Station Publication. University of Minnesota, St. Paul, MN [Online]. https://varietytrials.umn.edu/spring-wheat.
- Smith K., R. Dill-Macky, D. Von Ruckert, J.J. Wiersma. 2021. Oat. In: 2021 Minnesota Field Crop Variety Trials. Minnesota Agricultural Experiment Station Publication. University of Minnesota, St. Paul, MN [Online]. https://varietytrials.umn.edu/barley.
- Smith, K., R. Dill-Macky, J.J. Wiersma, B. Steffenson, K. Beaubien, and E. Schiefelbein. 2021. Barley. In: 2021 Minnesota Field Crop Variety Trials. Minnesota Agricultural Experiment Station Publication. University of Minnesota, St. Paul, MN [Online]. https://varietytrials.umn.edu/oat.
- Wiersma, J.J. and J.A. Anderson. 2021. Hard Red Winter Wheat. In: 2021 Minnesota Field Crop Trials. Minnesota Agricultural Experiment Station Publication. University of Minnesota, St. Paul, MN [Online]. https://varietytrials.umn.edu/winter-wheat.
- Wiersma, J.J. 2021 Winter Rye. In: 2021 Minnesota Field Crop Trials. Minnesota Agricultural Experiment Station Publication MP 121-2021. University of Minnesota, St. Paul, MN [Online] https://varietytrials.umn.edu/winter-rye.

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Table 1 - Preliminary summary of grain yield of spring wheat varieties tested in performance evaluations in six locations across southern Minnesota in 2022.

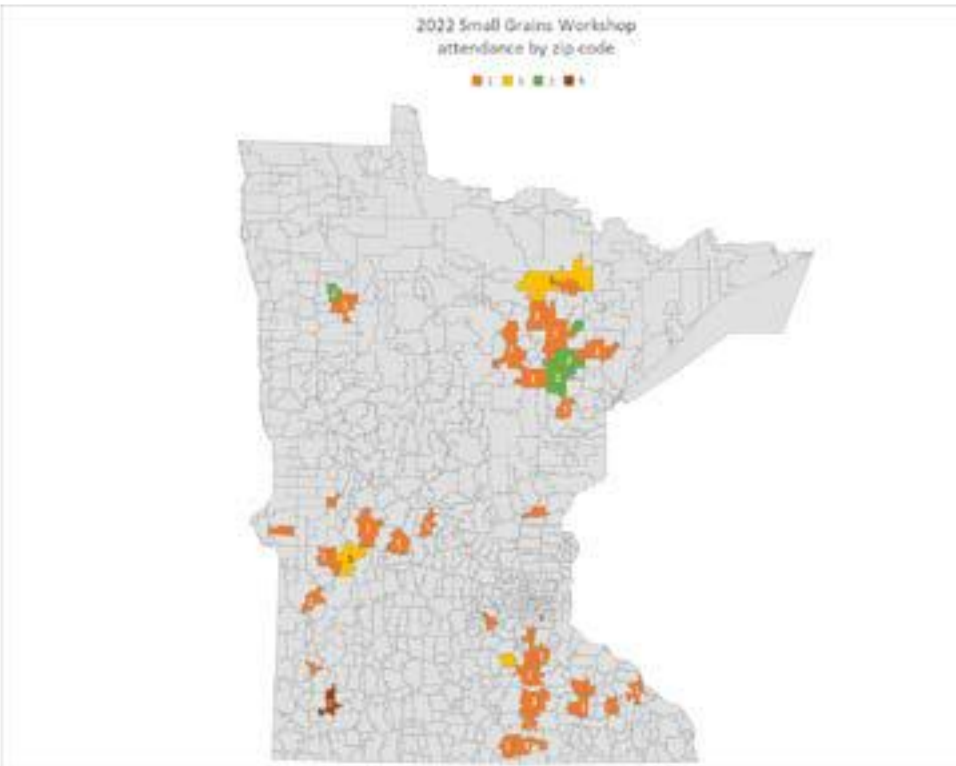
Entry	Becker (Irrigated)	LeCenter	Lamberton	Morris	St. Paul	Waseca	Average
	(bu/acre)	(bu/acre)	(bu/acre)	(bu/acre)	(bu/acre)	(bu/acre)	(bu/acre)
AP Gunsmoke CL25	62.3	81.0	68.7	67.3	56.6	38.5	62.3
AP Murdock	55.9	84.4	60.3	65.6	41.9	41.9	58.2
AP Smith	60.0	81.0	59.7	53.6	50.3	39.2	57.0
Ascend-SD	71.1	86.0	66.9	75.8	50.8	46.9	66.3
Bolles	55.9	74.4	53.1	54.2	46.1	36.6	53.5
CAG Justify	61.2	86.8	68.7	75.8	57.6	43.8	65.8
CAG Reckless	65.9	79.4	65.7	67.3	59.2	37.7	62.3
CAG Recoil	44.1	88.5	56.1	60.4	45.6	39.6	55.9
CP3099A	55.3	91.0	69.9	54.7	48.7	42.7	60.5
CP3119A	52.9	94.3	54.3	43.3	48.2	38.5	55.3
CP3188	58.2	85.2	54.3	65.0	50.8	37.3	58.2
CP3530	57.6	88.5	60.9	61.0	56.6	41.1	61.1
CP3915	59.4	77.7	63.9	50.7	60.8	32.4	57.6
CPX39120	37.0	100.1	63.9	47.9	39.3	28.2	53.0
Driver	62.9	85.2	64.5	63.3	63.9	36.6	62.9
Dyna-Gro Ambush	64.1	87.7	66.9	62.7	54.5	42.7	62.9
Dyna-Gro Ballistic	54.1	81.9	63.3	59.9	59.2	39.6	59.4
Dyna-Gro Commander	56.4	79.4	54.3	61.0	57.6	42.7	58.8
Lang-MN	55.9	76.9	55.5	56.4	53.4	40.4	56.5
LCS Ascent	67.6	83.5	59.7	63.8	61.3	37.0	62.3
LCS Buster	62.3	89.3	62.7	56.4	52.4	42.3	61.1
LCS Cannon	72.3	81.0	63.9	66.1	71.8	42.3	66.3
LCS Dual	69.4	80.2	63.9	61.0	51.9	45.7	62.3
LCS Trigger	57.6	90.1	66.3	63.8	52.4	44.2	62.3
Linkert	61.2	73.6	58.5	54.7	57.1	34.3	56.5
MN-Rothsay	59.4	76.9	52.5	53.6	46.6	42.3	55.3
MN-Torgy	62.9	83.5	63.9	52.4	33.5	40.0	55.9
MN-Washburn	57.0	81.9	62.1	57.0	52.9	32.0	57.0
MS Barracuda	66.4	81.0	56.7	52.4	66.0	37.7	59.9
MS Charger	72.9	88.5	68.1	64.4	63.4	44.2	66.9
MS Cobra	64.7	81.0	62.1	49.6	60.8	39.6	59.4
MS Ranchero	48.8	75.3	48.8	38.8	40.9	29.7	47.1
ND Frohberg	60.6	73.6	58.5	59.3	58.2	40.0	58.2
ND Heron	64.1	74.4	56.1	54.2	63.4	37.3	58.2
Prosper	57.0	84.4	63.3	67.3	50.3	35.1	59.4
Shelly	53.5	80.2	66.3	54.7	56.1	36.2	58.2
SY 611 CL25	68.2	79.4	58.5	56.4	54.0	40.4	59.4
SY Longmire6	45.9	78.6	53.7	50.7	51.4	29.3	51.8
SY McCloud	62.9	82.7	60.9	54.7	54.5	29.7	57.6
SY Valda	59.4	91.0	60.3	58.1	60.3	40.4	61.7
TCG-Heartland	59.4	81.0	53.1	49.0	56.1	40.0	56.5
TCG-Spitfire	65.9	93.5	66.9	61.6	57.6	41.1	64.6
TCG-Wildcat	67.6	85.2	62.7	70.1	48.2	39.6	62.3
WB9479	58.8	77.7	59.7	53.0	55.0	38.9	57.0
WB9590	62.9	81.9	53.1	55.9	58.7	38.1	58.2
Mean (bu/acre)	58.8	82.7	60.3	57.0	52.4	38.1	58.2
LSD (0.1)	11.1	9.8	7.7	10.5	8.3	5.3	3.1

Table 2 - Preliminary summary of grain yield of winter wheat va
evaluations in two locations across Minnesota in 2022.

Entry	Becker (Irrigated)	LeCenter
	(bu/acre)	(bu/acre)
AAC Goldrush	63.2	54.4
AAC Vortex	61.6	60.1
AC Emerson	58.9	52.8
AP Bigfoot	75.5	70.1
Bobcat	63.0	47.1
Flathead	71.8	62.9
FourOSix	74.4	59.8
Jerry	71.9	54.4
Jupiter[1]	94.4	70.8
Keldin	72.8	65.3
Minter	44.1	47.2
MS Iceman	73.4	64.7
ND Noreen	71.7	64.0
Redfield	80.4	66.5
Ruth	78.1	69.9
SD Andes	76.4	66.4
SD Midland	84.8	65.4
SY Wolverine	83.9	80.3
SY100[2]	93.8	67.5
Thompson	65.2	66.2
Viking 211	80.5	66.7
WB4309	84.1	74.2
Whitetail	76.9	62.3
Winner	80.1	73.9
Mean (bu/acre)	74.2	63.9
LSD(0.01)	11.3	7.8

[1] Soft white winter wheat
[2] Soft red winter wheat

Figure 1: Zip code map of those who attended one of the small grain workshops sponsored by this grant and completed the evaluation survey.



2022 Wheat, Barley, and Oats Variety Performance in Minnesota - Preliminary Report 24

Preface by Jochum Wiersma

'Dumbfounded' and 'befuddled' are the two adjectives that come to mind when reviewing the 2022 growing season. While there are parallels to the 2012 and 2013 growing seasons, the 2021 and 2022 growing seasons were extremer in every way compared to the aforementioned pair nearly a decade ago. The spring was cold and wet. Many producers commented to me that they could not recall ever getting started this late and with such difficult seedbed conditions. By the middle of May, only 5% of the spring wheat acres had been seeded. Two weeks later only half the acres had been seeded, compared to 2021, when the half way mark was reached four weeks earlier. Planting continued well past the date for full crop insurance coverage and ultimately, only a very limited number of acres were not seeded.

The first half of June remained cooler than normal and allowed ample tillering for the earliest seeded wheat. The second half of June, however, broke with the first half of the month and set the trend for the remainder of the summer with average temperatures slightly to well above the climate normal. Relative humidity and dew points were higher too than they had been the past few seasons. The disease risk models in turn indicated moderate to high risk for not just tan spot but, more importantly, Fusarium head blight (FHB) just as the majority of the spring wheat crop reached anthesis.

Many, including me, were only hoping for something a bit better than last year's disappointing numbers while keeping their fingers crossed that incidence of FHB would be low enough to avoid discounts. That was until the first combines started rolling. Initial yield reports were astoundingly good, and concerns of discounts for low-test weight and/or presence of DON were unnecessary. The only surprises 2022 did yield were some reports of ergot in the earliest harvested spring wheat and barley and lodging in later seeded fields in the central Red River Valley due to Hessian fly. USDA-NASS' initial spring wheat yield forecast for Minnesota on July 1 was 53 bu/acre or 13 bu/acre more than their 2021 forecast. USDA-NASS corrected their forecast upwards to 56 bu/acre one month later.

In the September Small Grains Summary USDA-NASS reported Minnesota's average spring wheat yield to be 61 bu/acre or nearly 30% higher than the year before. The state's average barley yield increased year-over-year by the same percentage point to 72.0 bu/acre, while the state average for oat increased 2 bu/acre to 59 bu/acre. Acreage of all three commodities remain near historic lows with only 55,000, 140,000, and 1.2 million acres of barley, oats, and spring wheat harvested, respectively.

Introduction:
Successful small grain production begins with selection of the best varieties for a particular farm or field. For that reason, varieties are compared in trial plots on the Minnesota Agricultural Experiment Station (MAES) sites at St. Paul, Waseca, Lamberton, Morris, and Crookston. In addition to these five MAES locations, trials are also planted at the Magnusson Research Farm near Roseau and with a number of farmer cooperators. The cooperator plots are handled so factors affecting yield and performance are as close to uniform for all entries at each location as possible.

The MAES 2022 Wheat, Barley, and Oat Variety Performance in Minnesota Preliminary Report 24 is presented under authority granted by the Hatch Act of 1887 to the Minnesota Agricultural Experiment Station to conduct performance trials on farm crops and interpret data for the public.

Variety Classifications:
Varieties are listed in the tables alphabetically. Seed of tested varieties can be eligible for certification, and use of certified seed is encouraged. However, certification

does not imply a recommendation. The intellectual property rights of the breeders or owners of the variety are listed as either PVP, PVP(pending), PVP(94), patent, or none. PVP protection means that the a variety is protected under the Plant Variety Protection Act for a period of 20 years, while PVP(94) means that the variety is protected for 20 years with the additional stipulation that seed of the variety can only be sold as registered and certified classes of seed. PVP(pending) indicates that the PVP application has been made and that you should consider the variety to have the same intellectual property rights as those provided by PVP(94). The designation of 'Patent' means that the variety is protected by a utility patent and that farm-saved seed may be prohibited by the patent holder. The designation 'None' means that the breeder or owner never requested any intellectual property protection or that legal protection has expired. Registered and certified seed is available from seed dealers or from growers listed in the 'Minnesota Crop Improvement Association 2022 Directory', available through the Minnesota Crop Improvement Association office in St. Paul or online at http://www.mncia.org

Interpretation of the Data:
The presented data are the preliminary variety trial information for single (2022) and multiple year (2020-2022) comparisons in Minnesota. The yields are reported as a percentage of the location mean, with the overall mean (bu/acre) listed below. Two-year and especially one-year data are less reliable and should be interpreted with caution. In contrast, averages across multiple environments, whether they are different years and/or locations, provide a more reliable estimate of mean performance and are more predictive of what you may expect from the variety the next growing season. The least significant difference or LSD is a statistical method to determine whether the observed yield difference between any two varieties is due to true, genetic differences between the varieties or due to experimental error. If the difference in yield between two varieties equals or exceeds the LSD value, the higher yielding one was indeed superior in yield. If the difference is less, the yield difference may have been due to chance rather than genetic differences, and we are unable to differentiate the two varieties. The 5% or 10% unit indicates that, with either 95% or 90% confidence, the observed difference is indeed a true difference in performance. Lowering this confidence level will allow more varieties to appear different from each other, but also increases the chances that false conclusions are drawn.

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Karen Beaubien, Matt Bickell, Dave Grafstrom, Tom Hoverstad, Michael Leiseth, Houston Lindell, Steve Quiring, Curt Reese, Susan Reynolds, Dimitri von Ruckert, Edward Schiefelbein, Nathan Stuart, Donn Vellekson, and Joe Wodarek supervised fieldwork at the various sites. Special thanks are also due to all cooperating producers.

SPRING WHEAT
James Anderson, Jochum Wiersma, Susan Reynolds, Nathan Stuart, Houston Lindell, Ruth Dill-Macky, James Kolmer, Matt Rouse, and Yue Jin.

MN-Torgy jumped from fifth to first place in its third year of production with just over a fifth of Minnesota's 1.2 million acres of HRSW. WB9590 was a close second with a slight increase in overall acreage and the most widely grown variety in much of the Red River Valley. SY Valda maintained its third place ranking with 11% of the acreage.

First-time entrants in the 2022 trials were Ascend-SD, CAG Recoil, CPX39120, LCS Ascent, MN-Rothsay, MS Charger, and ND-Heron. Ascend-SD and MN-Rothsay were tested under number in prior years and their 2 and 3 year averages are reported, respectively as well. WestBred did not enter any HRSW varieties in the University of Minnesota variety trial system. WB9479, WB9590, however, were included in the testing in 2022 as they each occupied more than 5% of the acreage in 2021.

Continued on next page →

The results of the variety performance evaluations for spring wheat are summarized in Tables 1 through 7. The varietal characteristics are presented in Tables 1 through 3. Tables 4, 5, and 6 present the relative grain yield of tested varieties in 1, 2, and 3-year comparisons. Table 7 presents the grain yield when fungal pathogens are controlled to the maximum extent possible compared to the same trials without the use of fungicides. The average yield across the six southern testing locations was 60 bu/acre in 2022. This average compares to a southern average of 56 bu/acre in 2021 and a three-year average of 58 bu/acre. The eight northern locations averaged 77 bu/acre in 2022 compared to 72 bu/acre last year and 85 bu/acre for the three-year average. Newcomers Ascend-SD, CP3099A, CP3119A, and MS Charger were among the highest yielding varieties in single year comparisons in both the north and southern portions of the state. LCS Trigger once again held the top spot for grain yield in both single and the multiple year comparisons. Higher yielding cultivars tend to be lower in grain protein. Variety selection is one approach to avoid discounts for low protein, but N fertility management remains paramount to maximize grain yield and grain protein.

Varieties with a lodging score of 2 and 3 are considered exceptionally good and will only lodge in extreme cases, while varieties with a rating of 4 or 5 have adequate straw strength most years. Increasing seeding rates generally increases the risk of lodging for all but the strongest and shortest semi-dwarf HRSW varieties. Conversely, lower seeding rates will lower the risk of lodging, but commonly results in lower grain yield potential. Linkert remains superior for straw strength varieties amongst public releases while MS-Washburn and MN-Rothsay are the only public release with a lodging rating of 3. Private releases that have superior lodging ratings include AP Smith, CP3915, MS Barracuda, SY Longmire and all entries in the variety trials from 21st Century Genetics (TCG) and WestBred.

Varieties with disease ratings of 4 or lower are considered the best defense against a particular disease. Varieties that are rated 7 or higher are likely to suffer significant economic losses under even moderate disease pressure. The foliar disease rating represents the total complex of leaf diseases other than the rusts, and includes the Septoria complex and tan spot. Although varieties may differ from their response to each of those diseases, the rating does not differentiate among them. Therefore, the rating should be used as a general indication and only for varietal selection in areas where these diseases historically have been a problem or if the previous crop is wheat or barley. Control of leaf diseases with fungicides may be warranted, even for those varieties with an above average rating.

Bacterial leaf streak (BLS) cannot be controlled with fungicides. Selection of more resistant varieties is the only recommended practice at this time if you have a history of problems with this disease. CAG Reckless, CP3530, CP3915, Driver, Dyna-Gro Ballistic, Lang-MN, LCS Trigger, MN-Torgy, MN-Washburn, ND Frohberg, SY Longmire, and TCG-Spitfire provide the best resistance against BLS.

Lang-MN, LCS Buster, LCS Trigger, and MN-Torgy provide the best resistance against FHB while another fifteen varieties have a rating of 4 for FHB. Combined, this group of varieties includes some of the top yielders and varieties with higher grain protein.

BARLEY

Kevin Smith, Ruth Dill-Macky, Jochum Wiersma, Brian Steffenson, Karen Beaubien and Ed Schiefelbein

The results of the variety performance evaluations for spring barley are summarized in Tables 8 through 12. The varietal characteristics and disease reactions are presented in Tables 8 and 9. Tables 10 through 12 present the relative grain yield of the tested varieties in single and multiple year comparisons. The average yield across the 13 testing locations was 101 bu/acre in 2022 (Table 12). This is up from a state average of 80 bu/A in 2021. The highest yields this year were recorded in Roseau with 132 bu/A (Table 10) while the lowest grain yields were recorded in St. Paul with 62 bu/A (Table 11).

Rasmusson was the highest yielding six-row variety and AAC Synergy, Brewski, and ND Genesis were the highest yielding two-row varieties based on the 2022 state average (Table 12). In general, the six-row varieties, except for Quest, had lower stem breakage (Table 8). In general, two-rows headed later than six-rows with the exception of Conlon which is the earliest maturity two-row variety tested.

Table 9 describes the reaction of this year's entries to five major diseases in the region. Disease reaction is based on data from at least two experiments (except spot blotch) and scored from 1–9; where 1 is most resistant and 9 is most susceptible. The varieties tested differed widely for resistance to spot blotch with most six-rows having good resistance (except Quest), while the two rows varied over the entire range of the rating scale 1-9. Net blotch can be an important disease and most varieties tested have good resistance with the exceptions of Brewski and Pinnacle. It is notable that Pinnacle is highly susceptible to net blotch. Conlon continues to be the variety with the best resistance to Fusarium head blight expressed as lower concentrations of vomitoxin or DON. All the varieties tested are generally susceptible (ratings from 3-6) to the QCCJ race of stem rust which has not been identified as a threat in the Midwest yet. All listed varieties carry stem rust resistance to the predominate Puccinia graminis f. sp. tritici race (MCCF). Most varieties possess pre-heading resistance to stem rust; thus, they will not likely incur much damage unless the disease epidemic is severe. Bacterial Leaf Streak (BLS) cannot be controlled by fungicides and there are some modest differences (ratings from 3-6) in resistance among the tested varieties.

OATS

Kevin P. Smith, Ruth Dill-Macky, Dimitri von Ruckert, Karen Beaubien, Jochum Wiersma

Entries in the state oat variety trial were evaluated in 9 locations. In addition, entries were evaluated for disease resistance to crown rust, barley yellow dwarf virus (BYDV), and smut in dedicated, inoculated nurseries. The results of the variety evaluations are summarized in Tables 13 to 17. The origin and agronomic characteristics of the tested oat varieties are listed in Table 13. Maturity, height, and test weight data are presented as statewide averages from 2020-2022 except where noted. Lodging data is also a statewide average from the same period, but only from locations where lodging was present. Maturity, height, and lodging are important considerations for variety selection based on the intended location and expected end use of the crop.

Crown rust continues to be a major limiting factor to oat production in Minnesota that must be managed to achieve optimal yield. Buckthorn (Rhamnus cathartica L.), the alternate host of crown rust is widespread in Minnesota, allowing for a persistent and particularly aggressive pathogen population. Rust in all yield trials was managed through treatment with a propiconazole-based fungicide when the flag leaf was fully extended (Feekes 9) to evaluate the yield potential with little to no disease. Crown rust and other disease resistance ratings are listed in Table 14. All disease scores were converted to a 1- 9 scale. A score of 1 is very resistant and a score of 9 is very susceptible. The most economical way of controlling crown rust is through resistant varieties; however, application of fungicide to a variety with rating of 4 or greater is prudent if crown rust is present in the lower canopy at Feekes 9. MN-Pearl, SD Buffalo and Warrior appear to be the best varieties for crown rust resistance.

Other important diseases include BYDV and smut which were evaluated in inoculated nurseries at the University of Illinois and the University of Minnesota, respectively. We observed little difference among the tested varieties for resistance to BYDV (ratings from 3-4). Most varieties tested had good resistance to smut with the exceptions of SD Buffalo and ND Heart. A seed treatment and certified seed should be used to manage smut. Choose the varieties with the lowest disease ratings in an organic production system and plant as early as possible to reduce the risk of yield losses caused by these diseases.

For grain production, lodging and grain quality traits should be considered when choosing a variety (Table 13). Oat varieties with high protein and low oil are preferred in the food market. High test weight, as a proxy for milling yield, is very important in both the food and feed markets. Contact your local elevator or buyer and ask whether they prefer particular varieties.

Tables 15 through 17 present the relative grain yield of the tested varieties in single and multiple year comparisons. For 2022, the highest yields were in Roseau and the lowest yields in Waseca. WIX10305-4 followed by SD Buffalo and Hayden were the top yielding varieties in statewide averages for 2022. These same three varieties performed well in both the northern and southern regions in 2021. Some varieties perform differently in the north and south. For example, in 2022 MN-Pearl was the highest yielding variety in the north but yielded lower in the south. In general, earlier maturing varieties perform better in southern Minnesota because flowering can occur when it is cooler. Similarly, later performing varieties tend to perform better in northern Minnesota.

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Table 1. Origin and agronomic characteristics of hard red spring wheat varieties in Minnesota in single-year (2022) and multiple-year comparisons.

Entry	Origin[1]	Legal Status	Desired Stand (Plants/Acre)[2]	Days to Heading[3]	Height Inches[3]	Straw Strength[4]
AP Gunsmoke CL2[5]	2021 AgriPro/Syngenta	PVP (94)	1.3	49.0	26.5	5
AP Murdock	2020 AgriPro/Syngenta	PVP (94)	1.3	48.8	25.0	5
AP Smith	2021 AgriPro/Syngenta	PVP (94)	1.3	51.7	24.3	2
Ascend-SD	2021 SDSU	PVP (94) pending	1.3	50.0	29.4	5–6
Bolles	2015 MN	PVP (94)	1.3	51.3	28.1	4
CAG Justify	2021 Champions Alliance Group	PVP (94)	1.2	51.1	27.5	5
CAG Reckless	2021 Champions Alliance Group	PVP (94)	1.3	49.8	28.2	5
CAG Recoil	2022 Champions Alliance Group	PVP (94) pending	1.3	55.2	27.2	3–4
CP3099A	2020 CROPLAN	PVP (94) pending	1.3	53.8	28.6	4–5
CP3119A	2021 CROPLAN	PVP (94) pending	1.3	54.8	27.9	2–3
CP3188	2020 CROPLAN	PVP (94) pending	1.3	50.2	28.3	5
CP3530	2015 CROPLAN	Patented	1.3	50.8	29.5	5
CP3915	2019 CROPLAN	PVP (94) pending	1.3	49.9	26.4	3
CPX39120	2023 CROPLAN	PVP (94) pending	1.3	57.6	29.5	5
Driver	2020 SDSU	PVP (94)	1.3	50.5	28.9	4
Dyna-Gro Ambush	2016 Dyna-Gro	PVP (94)	1.5	50.6	27.8	5
Dyna-Gro Ballistic	2018 Dyna-Gro	PVP (94)	1.5	48.2	27.4	5
Dyna-Gro Commander	2019 Dyna-Gro	PVP (94)	1.5	48.5	26.7	4
Lang-MN	2017 MN	PVP (94)	1.3	50.9	27.8	4
LCS Ascent	2022 Limagrain Cereal Seeds	PVP (94)	1.4	47.3	27.9	5
LCS Buster	2020 Limagrain Cereal Seeds	PVP (94)	1.3	52.8	27.5	4–5
LCS Cannon	2018 Limagrain Cereal Seeds	PVP (94)	1.4	46.8	27.8	4
LCS Dual	2021 Limagrain Cereal Seeds	PVP (94)	1.4	48.3	28.1	3–4
LCS Trigger	2016 Limagrain Cereal Seeds	PVP (94)	1.3	53.3	27.4	5
Linkert	2013 MN	PVP (94)	1.3	49.5	25.8	2
MN-Rothsay	2022 MN	PVP (94) pending	1.3	51.4	25.4	3
MN-Torgy	2020 MN	PVP (94)	1.3	50.7	26.1	4
MN-Washburn	2019 MN	PVP (94)	1.3	50.8	26.8	3
MS Barracuda	2018 Meridian Seeds	PVP (94)	1.3	46.8	26.6	3
MS Charger	2023 Meridian Seeds	PVP (94) pending	1.3	48.2	26.7	4–5
MS Cobra	2022 Meridian Seeds	PVP (94)	1.3	48.6	26.7	3–4
MS Ranchero	2020 Meridian Seeds	PVP (94)	1.3	53.3	28.5	6
ND Frohberg	2020 NDSU	PVP (94)	1.3	49.5	28.7	5
ND Heron	2021 NDSU	PVP (94) pending	1.3	47.7	28.7	5–6
Prosper	2011 NDSU	PVP (94)	1.3	50.8	27.5	6
Shelly	2016 MN	PVP (94)	1.3	50.9	25.7	5
SY 611 CL2[5]	2019 AgriPro/Syngenta	PVP (94)	1.3	48.6	24.9	4
SY Longmire[6]	2019 AgriPro/Syngenta	PVP (94)	1.3	50.0	26.3	3
SY McCloud	2019 AgriPro/Syngenta	PVP (94)	1.3	49.3	26.6	4
SY Valda	2015 AgriPro/Syngenta	PVP (94)	1.3	50.4	25.2	5
TCG-Heartland	2019 21st Century Genetics	PVP (94), Patent pending	1.6	47.8	24.4	3
TCG-Spitfire	2016 21st Century Genetics	PVP (94)	1.5	51.7	27.5	3
TCG-Wildcat	2020 21st Century Genetics	PVP (94), Patent pending	1.5	50.3	26.5	3
WB9479	2017 WestBred	Patented, PVP (94)	1.3	48.6	24.7	3
WB9590	2017 WestBred	Patented, PVP (94)	1.3	48.6	23.9	3
Mean						

[1] Abbreviations: MN = Minnesota Agricultural Experiment Station; NDSU = North Dakota State University Research Foundation; SDSU = South Dakota

[2] Our standard seeding rate is designed to achieve a desired stand of 1.3 million plants/acre, assuming a 20% stand loss and adjusting for the germination

[3] 2022 data

[4] 1-9 scale in which 1 is the strongest straw and 9 is the weakest. Based on 2014-2022 data. The rating of newer entries may change by as much as one rating point as more data are collected.

[5] AP Gunsmoke CL2 and SY 611 CL2 have tolerance to Beyond® herbicide.

[6] SY Longmire has solid stems.

Table 2. Grain quality of hard red spring wheat varieties in Minnesota in single-year (2022) and multiple-year comparisons.

	Test Weight (lb/Bu)		Protein (%)[1]		Baking	Pre-Harvest
Entry	2022	2 yr	2022	2 yr	Quality[2]	Sprouting[3]
AP Gunsmoke CL2	58.7	59.7	15.7	15.3	5	3
AP Murdock	59.4	60.2	14.2	14.5	5	1
AP Smith	58.8	60.2	15.5	15.2	3	4
Ascend-SD	59.1	60.3	15.2	14.8	–	*4*
Bolles	58.9	60.1	16.8	16.7	1	1
CAG Justify	58.2	58.7	13.8	13.9	–	3
CAG Reckless	59.9	61.1	15.1	15.0	–	*4*
CAG Recoil	59.2	–	14.6	–	–	1
CP3099A	57.0	58.1	13.1	13.0	*6*	*1*
CP3119A	54.5	55.8	13.9	13.6	–	*3*
CP3188	57.3	58.5	13.8	13.6	–	*1*
CP3530	59.5	60.1	15.2	15.1	3	1
CP3915	59.0	60.6	15.2	15.1	4	1
CPX39120	52.6	–	13.9	–	–	2
Driver	60.5	61.8	14.8	14.4	6	3
Dyna-Gro Ambush	58.6	60.5	14.4	14.6	2	3
Dyna-Gro Ballistic	60.2	60.6	14.9	14.5	5	3
Dyna-Gro Commander	59.1	60.6	15.2	15.0	6	1
Lang-MN	59.9	60.8	15.2	15.1	3	1
LCS Ascent	59.8	–	14.6	–	–	2
LCS Buster	56.8	57.9	12.6	12.7	7	4
LCS Cannon	60.8	62.1	14.8	14.7	4	3
LCS Dual	59.2	–	14.6	–	–	2
LCS Trigger	59.4	60.2	13.1	13.3	7	2
Linkert	60.0	61.3	15.6	15.7	1	1
MN-Rothsay	59.5	60.7	14.8	14.8	5	2
MN-Torgy	59.5	61.0	15.1	15.2	4	1
MN-Washburn	58.8	60.2	14.8	14.6	3	1
MS Barracuda	58.6	60.4	15.9	15.4	4	3
MS Charger	58.9	–	13.6	–	–	1
MS Cobra	58.9	60.6	15.1	14.9	–	*4*
MS Ranchero	56.9	59.0	15.0	14.5	6	4
ND Frohberg	59.8	61.0	15.0	14.9	3	4
ND Heron	60.5	–	15.3	–	–	1
Prosper	59.4	60.2	14.1	14.2	5	1
Shelly	58.9	60.6	14.7	14.4	5	1
SY 611 CL2	59.1	60.7	15.1	14.9	6	2
SY Longmire	58.0	60.0	15.8	15.3	3	3
SY McCloud	60.7	61.8	15.4	15.5	3	2
SY Valda	59.1	60.5	14.7	14.4	6	2
TCG-Heartland	59.2	60.9	15.6	15.5	2	1
TCG-Spitfire	58.2	59.5	14.3	14.2	3	4
TCG-Wildcat	60.0	61.1	15.2	15.0	4	1
WB9479	58.6	60.3	16.1	15.9	2	1
WB9590	58.8	60.4	15.7	15.5	4	1
Mean	58.8	60.1	14.9	14.8		
No. Environments	6	17	6	17		

[1] 12% moisture basis.

[2] 2014-2021 crop years, where applicable

[3] 1-9 scale in which 1 is best and 9 is worst. Values of 1-2 should be considered as resistant.

Continued on next page

Table 3. Disease reactions[1] of hard red spring wheat varieties in Minnesota in multiple-year comparisons.

Entry	Leaf Rust	Stripe Rust[2]	Stem Rust[3]	Bacterial Leaf Streak[4]	Other Leaf Diseases[5]	Scab
AP Gunsmoke CL2	3	–	1	8	7	5
AP Murdock	3	–	1	4	6	7
AP Smith	6	–	1	4	5	6
Ascend-SD	*3*	–	*1*	*2–3*	*6*	*4*
Bolles	2	1	2	4	4	5
CAG Justify	3	–	2	4–5	4	4
CAG Reckless	*1*	–	*1*	*3*	*5*	*4*
CAG Recoil	2	–	2	2–3	5	–
CP3099A	*6*	–	*8*	*6–7*	*4*	*5–6*
CP3119A	*5*	–	*2*	*6–7*	*4*	*5–6*
CP3188	*1*	–	*6*	*6–7*	*6*	*5*
CP3530	7	3	1	3	6	4
CP3915	1	–	1	2	5	4
CPX39120	7	–	6	4–5	3	–
Driver	3	–	1	3	4	4
Dyna-Gro Ambush	4	–	2	4	4	4
Dyna-Gro Ballistic	4	–	3	3	4	5
Dyna-Gro Commander	2	–	1	4	6	5
Lang-MN	1	–	2	3	4	3
LCS Ascent	4	–	1–2	6–7	5	–
LCS Buster	3	–	1	4	3	3
LCS Cannon	4	–	2	5	7	5
LCS Dual	3	–	1–2	5	4	–
LCS Trigger	1	–	2	2	3	3
Linkert	3	1	1	5	5	5
MN-Rothsay	4	–	2	4	3	4
MN-Torgy	3	–	1	3	4	3
MN-Washburn	1	2	1	3	4	4
MS Barracuda	6	–	2	7	5	5
MS Charger	–	–	2	5	6	–
MS Cobra	*2*	–	*1*	*4–5*	*4*	*5*
MS Ranchero	3	–	1	6	3	4
ND Frohberg	3	–	1	3	5	5
ND Heron	5	–	1–2	5	4	–
Prosper	6	5	2	4	5	5
Shelly	5	1	2	6	4	4
SY 611 CL2	4	–	5	4	4	4
SY Longmire	5	–	1	3	5	7
SY McCloud	3	–	1	6	6	4
SY Valda	4	2	1	4	5	4
TCG-Heartland	3	–	2	5	6	6
TCG-Spitfire	4	–	2	3	5	6
TCG-Wildcat	3	–	3	6	7	7
WB9479	6	–	2	6	6	7
WB9590	6	–	2	6	6	7

[1] 1-9 scale where 1=most resistant, 9=most susceptible.

[2] Based on natural infections in 2015 at Kimball, Lamberton, and Waseca.

[3] Stem rust levels have been very low in production fields in recent years, even on susceptible varieties.

[4] Bacterial leaf streak symptoms are highly variable from one environment to the next. The rating of entries may change as more data is collected.

[5] Combined rating of tan spot and septoria.

NOTES

Continued on next page

Table 4. Relative grain yield of hard red spring wheat varieties in northern Minnesota locations in single-year

Entry	Crookston			Fergus Falls			Hallock			Oklee		
	2022	2 Yr	3 Yr	2022	2 Yr	3 Yr	2022	2 Yr	3 Yr	2022	2 Yr	3 Yr
AP Gunsmoke CL2	95	100	102	102	101	101	99	100	101	102	105	110
AP Murdock	108	102	103	89	89	92	90	91	94	103	94	102
AP Smith	101	100	100	91	98	98	92	96	94	120	110	105
Ascend-SD	102	97	–	111	109	–	99	101	–	91	100	–
Bolles	96	94	94	91	96	94	90	89	91	89	90	91
CAG Justify	96	94	–	99	105	–	115	112	–	96	101	–
CAG Reckless	91	100	–	95	101	–	101	103	–	93	98	–
CAG Recoil	106	–	–	101	–	–	97	–	–	93	–	–
CP3099A	119	107	–	115	118	–	114	113	–	122	131	–
CP3119A	93	100	–	100	108	–	109	104	–	119	117	–
CP3188	105	108	–	90	99	–	91	96	–	98	102	–
CP3530	97	88	90	94	97	97	109	101	105	96	93	96
CP3915	97	93	96	96	96	98	98	102	99	100	97	94
CPX39120	66	–	–	106	–	–	95	–	–	105	–	–
Driver	105	103	102	107	108	107	102	102	107	108	114	112
Dyna-Gro Ambush	92	102	103	103	105	103	110	103	104	112	101	103
Dyna-Gro Ballistic	99	98	101	103	105	106	100	101	102	94	105	105
Dyna-Gro Commander	102	103	100	87	93	96	97	97	99	100	98	99
Lang-MN	105	104	103	102	98	99	102	100	101	92	91	93
LCS Ascent	97	–	–	95	–	–	105	–	–	104	–	–
LCS Buster	113	104	104	110	109	112	112	109	110	107	109	116
LCS Cannon	97	93	95	96	94	96	87	94	93	99	100	102
LCS Dual	102	–	–	102	–	–	105	–	–	84	–	–
LCS Trigger	111	106	108	107	102	108	117	109	116	119	110	114
Linkert	100	104	100	84	88	91	88	95	96	88	83	87
MN-Rothsay	106	111	110	98	100	103	114	107	106	107	107	107
MN-Torgy	105	105	105	99	99	102	106	102	100	82	88	95
MN-Washburn	101	97	97	113	102	101	99	100	100	80	88	92
MS Barracuda	97	91	92	97	96	96	90	96	96	92	101	102
MS Charger	116	–	–	108	–	–	106	–	–	109	–	–
MS Cobra	102	101	–	90	100	–	99	100	–	99	94	–
MS Ranchero	86	101	101	110	104	101	111	106	107	94	97	100
ND Frohberg	88	100	98	94	95	99	97	93	92	86	95	97
ND Heron	94	–	–	96	–	–	94	–	–	99	–	–
Prosper	92	93	98	115	113	112	106	104	105	109	106	108
Shelly	102	100	102	105	107	108	109	106	108	99	100	103
SY 611 CL2	98	96	98	107	110	108	93	99	97	108	105	108
SY Longmire	94	93	95	92	97	97	98	97	96	93	96	95
SY McCloud	106	107	102	99	98	99	92	97	100	94	97	99
SY Valda	91	92	96	106	101	103	108	107	108	105	107	105
TCG-Heartland	94	97	98	93	93	96	89	91	90	91	93	94
TCG-Spitfire	108	103	105	101	109	109	96	100	98	101	97	100
TCG-Wildcat	108	100	101	88	97	99	99	99	99	99	100	99
WB9479	100	99	103	89	90	92	97	94	97	93	95	99
WB9590	100	99	104	105	104	103	102	98	105	106	98	101
Mean (Bu/Acre)	96.1	76.9	74.6	83.9	79.1	80.1	82.3	77.3	72.8	71.8	70.8	73.5
LSD (0.10)	9.0	9.5	6.2	14.6	6.4	4.3	20.0	6.0	5.1	18.9	7.5	5.7

(2022) and multiple-year comparisons (2020-2022).

Perley			Roseau			Stephen			Strathcona		
2022	**2 Yr**	**3 Yr**	**2022**	**2 Yr**	**3 Yr**	**2022**	**2 Yr**	**3 Yr**	**2022**	**2 Yr**	**3 Yr**
82	94	93	101	101	101	94	97	98	102	104	101
117	108	108	103	99	102	110	100	106	113	105	111
102	101	99	91	93	97	99	100	102	93	98	95
101	99	–	113	107	–	117	111	–	120	109	–
89	96	97	91	95	95	100	94	94	87	88	88
102	104	–	120	110	–	105	104	–	115	108	–
97	100	–	106	105	–	104	105	–	104	104	–
113	–	–	86	–	–	98	–	–	95	–	–
103	103	–	121	115	–	106	111	–	115	107	–
79	85	–	101	112	–	89	105	–	111	105	–
95	101	–	107	106	–	98	103	–	106	105	–
102	99	100	117	111	106	107	106	104	112	107	109
105	103	101	99	95	103	103	96	98	117	110	102
84	–	–	74	–	–	70	–	–	96	–	–
106	107	108	116	108	105	99	100	103	102	103	100
94	98	101	103	103	100	112	101	104	107	105	106
87	92	96	95	98	106	107	105	107	104	102	100
106	104	101	99	101	101	98	97	101	102	105	105
94	95	95	99	93	97	98	100	97	95	94	102
91	–	–	110	–	–	105	–	–	105	–	–
107	108	111	99	100	109	107	107	110	100	99	104
104	104	107	109	109	104	104	105	102	104	106	105
102	–	–	97	–	–	99	–	–	98	–	–
125	115	118	116	105	110	110	108	110	114	107	110
89	89	89	91	89	90	93	96	92	91	94	90
105	107	106	108	104	105	109	104	105	100	100	102
103	103	101	103	97	100	116	108	111	93	96	99
103	101	100	93	98	90	106	98	99	101	97	90
94	97	93	100	102	98	93	92	93	92	100	103
101	–	–	110	–	–	97	–	–	109	–	–
93	98	–	97	101	–	95	94	–	94	97	–
90	95	97	96	101	105	87	88	97	109	105	113
88	92	92	105	102	99	84	88	88	89	95	96
86	–	–	111	–	–	94	–	–	93	–	–
94	101	101	98	102	105	109	110	111	104	99	99
102	97	96	115	107	102	105	103	101	107	105	108
113	106	104	107	104	105	103	98	101	97	99	98
97	98	98	84	90	90	96	100	100	103	101	92
99	97	97	102	104	103	92	91	88	95	97	99
113	105	106	102	105	103	107	107	111	97	99	102
94	87	94	77	90	92	93	89	96	80	88	88
111	113	111	91	94	97	106	105	103	92	97	98
100	103	103	109	104	107	105	98	104	105	107	106
96	98	94	91	92	92	96	92	96	105	104	104
95	97	100	102	101	103	97	92	93	104	102	105
96.9	91.1	83.1	80.8	86.0	86.0	89.5	79.8	77.1	83.8	72.3	71.3
7.9	7.4	5.9	10.6	7.2	6.2	11.4	7.0	5.6	19.3	9.1	7.1

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Table 5. Relative grain yield of hard red spring wheat varieties in southern Minnes 2022).

Entry	Becker			Benson[1]	Le Center		
	2022	2 Yr	3 Yr	2 Yr	2022	2 Yr	3 Yr
AP Gunsmoke CL2	106	105	105	100	98	103	104
AP Murdock	95	99	99	93	102	98	102
AP Smith	102	98	98	104	98	100	99
Ascend-SD	121	115	–	–	104	103	–
Bolles	95	88	89	100	90	90	89
CAG Justify	104	97	–	–	105	97	–
CAG Reckless	112	118	–	–	96	96	–
CAG Recoil	75	–	–	–	107	–	–
CP3099A	94	98	–	–	110	101	–
CP3119A	90	104	–	–	114	110	–
CP3188	99	103	–	–	103	106	–
CP3530	98	97	97	107	107	108	107
CP3915	101	104	105	94	94	95	96
CPX39120	63	–	–	–	121	–	–
Driver	107	106	106	103	103	102	100
Dyna-Gro Ambush	109	102	102	104	106	108	107
Dyna-Gro Ballistic	92	101	101	105	99	101	103
Dyna-Gro Commander	96	103	103	112	96	101	102
Lang-MN	95	97	97	95	93	96	96
LCS Ascent	115	–	–	–	101	–	–
LCS Buster	106	114	115	105	108	104	105
LCS Cannon	123	114	114	101	98	104	107
LCS Dual	118	–	–	–	97	–	–
LCS Trigger	98	105	106	118	109	112	112
Linkert	104	102	102	97	89	94	93
MN-Rothsay	101	105	105	107	93	97	98
MN-Torgy	107	107	107	102	101	103	105
MN-Washburn	97	96	96	93	99	99	102
MS Barracuda	113	105	105	95	98	103	105
MS Charger	124	–	–	–	107	–	–
MS Cobra	110	105	–	–	98	101	–
MS Ranchero	83	87	87	102	91	96	95
ND Frohberg	103	102	103	104	89	95	96
ND Heron	109	–	–	–	90	–	–
Prosper	97	103	104	105	102	103	105
Shelly	91	94	94	107	97	101	104
SY 611 CL2	116	111	112	98	96	96	93
SY Longmire	78	90	90	94	95	96	95
SY McCloud	107	97	97	93	100	102	100
SY Valda	101	98	99	102	110	108	107
TCG-Heartland	101	97	97	95	98	98	98
TCG-Spitfire	112	110	111	109	113	110	107
TCG-Wildcat	115	112	112	96	103	103	104
WB9479	100	96	96	92	94	98	98
WB9590	107	98	99	98	99	100	103
Mean (Bu/Acre)	58.8	50.5	50.4	72.7	82.7	76.8	77.0
LSD (0.10)	18.9	10.9	7.6	6.6	11.8	6.0	3.6

1 2022 was abandoned due to early season flooding. 2 year datat is 2020-2021

2 2021 Waseca was discarded due to excessive within trial variation. 2 year is the mean of 2020 and 2022.

ota locations in single-year (2022) and multiple-year comparisons (2020-

Lamberton			Morris			St. Paul			Waseca[2]	
2022	2 Yr	3 Yr	2022	2 Yr	3 Yr	2022	2 Yr	3 Yr	2022	2 Yr
114	110	99	118	111	109	108	98	97	101	103
100	99	101	115	103	104	80	94	100	110	113
99	101	101	94	99	104	96	100	97	103	101
111	108	–	133	124	–	97	99	–	123	–
88	89	94	95	98	98	88	94	95	96	95
114	107	–	133	130	–	110	108	–	115	–
109	104	–	118	110	–	113	111	–	99	–
93	–	–	106	–	–	87	–	–	104	–
116	118	–	96	115	–	93	92	–	112	–
90	100	–	76	100	–	92	91	–	101	–
90	106	–	114	119	–	97	102	–	98	–
101	100	100	107	101	100	108	105	103	108	101
106	103	105	89	93	96	116	97	92	85	87
106	–	–	84	–	–	75	–	–	74	–
107	113	112	111	108	108	122	112	107	96	103
111	103	100	110	88	96	104	110	109	112	112
105	101	104	105	106	106	113	99	101	104	104
90	93	96	107	104	109	110	113	110	112	117
92	94	94	99	99	101	102	108	104	106	104
99	–	–	112	–	–	117	–	–	97	–
104	103	108	99	97	104	100	105	103	111	116
106	104	104	116	93	101	137	126	123	111	113
106	–	–	107	–	–	99	–	–	120	–
110	114	117	112	118	124	100	110	107	116	123
97	95	94	96	93	93	109	105	102	90	87
87	89	95	94	98	104	89	97	99	111	104
106	101	105	92	98	102	64	87	92	105	100
103	100	101	100	105	102	101	101	96	84	97
94	97	99	92	82	85	126	121	116	99	103
113	–	–	113	–	–	121	–	–	116	–
103	102	–	87	94	–	116	115	–	104	–
81	89	91	68	79	87	78	90	99	78	92
97	97	98	104	103	105	111	106	104	105	105
93	–	–	95	–	–	121	–	–	98	–
105	101	107	118	119	115	96	92	97	92	96
110	106	104	96	103	107	107	112	105	95	96
97	99	97	99	96	95	103	96	97	106	97
89	98	103	89	101	99	98	81	83	77	76
101	100	94	96	89	90	104	98	100	78	84
100	102	101	102	100	101	115	108	103	106	107
88	93	94	86	87	87	107	99	99	105	104
111	115	119	108	106	114	110	102	100	108	100
104	109	109	123	114	111	92	100	100	104	102
99	93	92	93	89	90	105	99	97	102	102
88	96	99	98	92	94	112	104	105	100	103
60.3	60.1	60.8	57.0	55.8	52.6	52.4	50.5	58.8	38.1	42.2
12.8	7.0	5.9	18.4	13.2	8.6	15.8	12.2	7.8	13.9	6.7

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Table 6. Relative grain yield of hard red spring wheat varieties in Minnesota in single-year (2022) and multiple-year comparisons (2020-2022).

	State			North			South		
Entry	**2022**	**2 Yr**	**3 Yr**	**2022**	**2 Yr**	**3 Yr**	**2022**	**2 Yr**	**3 Yr**
AP Gunsmoke CL2	100	101	101	97	100	101	107	104	102
AP Murdock	103	98	102	104	99	102	100	98	101
AP Smith	98	100	99	98	99	99	98	100	100
Ascend-SD	109	106	–	107	104	–	114	110	–
Bolles	92	93	93	92	93	93	92	93	94
CAG Justify	108	106	–	106	105	–	113	108	–
CAG Reckless	102	103	–	99	102	–	107	105	–
CAG Recoil	98	–	–	99	–	–	96	–	–
CP3099A	111	110	–	114	113	–	104	106	–
CP3119A	98	104	–	99	104	–	95	102	–
CP3188	99	104	–	99	102	–	100	107	–
CP3530	104	101	102	104	100	101	105	103	103
CP3915	101	98	98	102	99	99	99	97	96
CPX39120	88	–	–	86	–	–	91	–	–
Driver	106	106	105	105	105	105	108	107	105
Dyna-Gro Ambush	105	102	103	104	102	103	108	103	104
Dyna-Gro Ballistic	100	101	103	99	100	103	102	101	104
Dyna-Gro Commander	100	101	102	99	100	100	101	104	106
Lang-MN	98	97	98	98	97	98	97	98	98
LCS Ascent	103	–	–	101	–	–	107	–	–
LCS Buster	106	105	109	107	106	109	105	105	107
LCS Cannon	105	103	103	100	101	100	114	108	109
LCS Dual	102	–	–	99	–	–	107	–	–
LCS Trigger	112	109	113	115	108	112	107	112	115
Linkert	93	94	93	91	92	92	97	96	96
MN-Rothsay	102	103	104	106	105	105	95	98	101
MN-Torgy	100	100	102	101	100	102	96	100	102
MN-Washburn	99	98	97	100	98	96	98	99	99
MS Barracuda	97	98	98	94	97	97	103	100	101
MS Charger	110	–	–	107	–	–	115	–	–
MS Cobra	98	99	–	96	98	–	102	102	–
MS Ranchero	92	96	99	97	99	102	81	90	94
ND Frohberg	94	97	97	91	95	95	100	101	102
ND Heron	97	–	–	96	–	–	100	–	–
Prosper	103	103	105	103	103	105	102	103	105
Shelly	103	103	103	105	103	103	100	102	103
SY 611 CL2	103	102	101	103	102	102	102	100	98
SY Longmire	93	95	94	95	96	95	89	93	93
SY McCloud	98	98	97	98	99	98	99	96	95
SY Valda	104	103	104	104	103	104	106	103	103
TCG-Heartland	92	92	94	89	91	94	97	95	96
TCG-Spitfire	104	105	105	101	103	103	111	109	109
TCG-Wildcat	103	103	103	102	101	102	107	106	105
WB9479	97	95	96	96	95	97	98	95	95
WB9590	101	99	101	101	99	102	100	98	100
Mean (Bu/Acre)	73.9	69.8	69.9	85.6	79.2	77.3	58.2	57.2	59.9
LSD (0.10)	3.1	2.2	1.6	3.6	2.6	2.0	5.3	3.7	2.6
No. Environments	14	28	42	8	16	24	6	12	18

Table 7. Grain yield (bushels per acre) of hard red spring wheat varieties grown under conventional and intensive management.

	North						South						State					
	2022		2-year		3-year		2022		2-year		3-year		2022		2-year		3-year	
Entry	Conv	Int	Conv	Int	Conv	Int	Conv	Int	Conv	Int	Conv	Int	Conv	Int	Conv	Int	Conv	Int
AP Gunsmoke CL2	86.6	103.3	81.6	93.4	81.4	90.4	68.0	71.9	64.2	71.2	58.8	64.8	77.3	87.6	72.9	82.3	70.1	77.6
AP Murdock	93.4	108.4	81.6	89.8	82.6	90.4	62.8	65.3	58.7	63.4	58.1	60.6	78.1	86.8	70.1	76.6	70.3	75.5
AP Smith	85.2	97.7	78.4	85.7	78.9	82.8	56.5	65.0	58.1	66.5	57.8	61.4	70.8	81.3	68.2	76.1	68.4	72.1
Ascend-SD	94.4	104.2	83.5	95.5	–	–	71.4	75.3	67.3	72.9	–	–	82.9	89.7	75.4	84.2	–	–
Bolles	82.7	95.5	76.8	85.2	76.0	81.1	53.8	60.1	54.1	60.7	54.4	59.2	68.2	77.8	65.4	72.9	65.2	70.1
CAG Justify	94.8	108.5	83.3	98.6	–	–	72.2	68.4	68.5	69.3	–	–	83.5	88.4	75.9	84.0	–	–
CAG Reckless	86.4	94.1	83.5	88.0	–	–	66.4	68.1	62.2	64.6	–	–	76.4	81.1	72.8	76.3	–	–
CAG Recoil	86.0	95.3	–	–	–	–	58.3	61.2	–	–	–	–	72.2	78.2	–	–	–	–
CP3099A	106.1	116.2	90.5	102.2	–	–	62.3	68.7	67.4	78.1	–	–	84.2	92.4	79.0	90.2	–	–
CP3119A	85.6	104.2	86.4	102.6	–	–	49.0	58.4	58.1	68.0	–	–	67.3	81.3	72.3	85.3	–	–
CP3188	93.7	106.6	87.1	97.9	–	–	59.7	66.3	65.2	70.0	–	–	76.7	86.5	76.1	84.0	–	–
CP3530	93.7	103.3	81.5	89.6	78.9	88.3	60.9	59.9	58.4	62.2	56.7	60.4	77.3	81.6	70.0	75.9	67.8	74.4
CP3915	86.6	103.1	76.7	92.2	80.4	90.3	57.2	64.9	56.9	66.3	57.2	62.8	71.9	84.0	66.8	79.3	68.8	76.6
CPX39120	61.2	92.4	–	–	–	–	55.8	62.7	–	–	–	–	58.5	77.6	–	–	–	–
Driver	97.1	103.1	85.8	95.6	83.1	88.1	63.8	68.1	64.1	66.9	62.4	62.8	80.5	85.6	75.0	81.2	72.8	75.5
Dyna-Gro Ambush	85.6	101.0	83.3	89.7	81.4	85.3	64.6	72.9	55.4	68.6	55.8	64.0	75.1	86.9	69.3	79.2	68.6	74.6
Dyna-Gro Ballistic	85.9	99.5	79.8	93.4	83.0	89.3	61.4	67.5	59.9	67.2	59.7	66.0	73.7	83.5	69.8	80.3	71.4	77.6
Dyna-Gro Commander	88.8	101.0	83.0	92.0	80.8	87.1	57.9	63.3	57.2	64.1	58.0	61.8	73.3	82.2	70.1	78.1	69.4	74.5
Lang-MN	90.3	98.5	80.0	85.9	79.9	83.9	55.9	62.8	55.7	63.9	55.0	61.3	73.1	80.6	67.9	74.9	67.5	72.6
LCS Ascent	91.3	104.8	–	–	–	–	61.7	71.9	–	–	–	–	76.5	88.3	–	–	–	–
LCS Buster	94.2	107.6	83.3	97.7	85.5	94.0	59.6	69.0	58.2	73.8	60.4	70.2	76.9	88.3	70.8	85.7	73.0	82.1
LCS Cannon	90.5	102.8	82.8	92.6	80.1	87.9	65.1	69.9	57.1	70.8	58.1	66.2	77.8	86.4	70.0	81.7	69.1	77.1
LCS Dual	88.5	98.8	–	–	–	–	62.6	67.8	–	–	–	–	75.6	83.3	–	–	–	–
LCS Trigger	100.4	111.2	85.8	97.0	87.9	92.9	65.2	75.6	67.0	76.4	67.8	74.8	82.8	93.4	76.4	86.7	77.9	83.9
Linkert	84.9	93.4	78.4	81.5	76.2	80.8	56.4	64.1	54.7	65.2	53.1	60.5	70.6	78.8	66.5	73.4	64.7	70.7
MN-Rothsay	94.6	106.8	87.3	92.8	86.2	89.0	52.9	60.8	54.1	64.7	56.4	61.0	73.7	83.8	70.7	78.8	71.3	75.0
MN-Torgy	92.3	101.6	82.1	87.6	82.3	85.4	58.2	66.1	57.5	66.4	58.9	61.9	75.2	83.8	69.8	77.0	70.6	73.7
MN-Washburn	86.4	100.0	79.4	87.3	75.1	88.3	59.4	67.3	59.4	66.7	57.7	61.9	72.9	83.6	69.4	77.0	66.4	75.1
MS Barracuda	87.1	104.0	78.9	92.0	76.4	85.0	54.6	63.2	51.9	62.3	52.6	58.4	70.9	83.6	65.4	77.1	64.5	71.7
MS Charger	100.3	108.9	–	–	–	–	66.3	73.0	–	–	–	–	83.3	90.9	–	–	–	–
MS Cobra	88.3	98.0	82.1	89.2	–	–	55.9	62.5	56.7	64.6	–	–	72.1	80.2	69.4	76.9	–	–
MS Ranchero	79.9	85.2	82.2	83.4	82.8	81.5	44.0	60.8	48.9	62.3	50.6	56.9	62.0	73.0	65.5	72.9	66.7	69.2
ND Frohberg	84.5	90.7	82.1	85.8	79.3	81.7	58.7	65.6	57.9	63.8	57.9	61.0	71.6	78.2	70.0	74.8	68.6	71.4
ND Heron	90.0	94.6	–	–	–	–	55.1	65.4	–	–	–	–	72.5	80.0	–	–	–	–
Prosper	84.0	105.2	79.6	94.4	81.5	91.6	65.1	71.7	63.5	71.7	62.6	68.3	74.6	88.4	71.6	83.0	72.1	80.0
Shelly	95.4	106.7	84.5	94.7	81.9	92.6	60.8	64.6	60.6	69.0	59.9	63.0	78.1	85.6	72.5	81.8	70.9	77.8
SY 611 CL2	90.6	102.1	81.5	90.9	81.7	88.3	57.4	64.3	56.7	65.0	54.8	60.7	74.0	83.2	69.1	77.9	68.3	74.5
SY Longmire	79.4	92.0	74.5	84.4	74.1	82.9	52.1	52.5	57.8	60.8	57.4	59.0	65.8	72.3	66.1	72.6	65.7	70.9
SY McCloud	92.0	100.8	85.8	86.9	82.2	83.9	58.0	65.4	54.8	64.5	52.4	58.7	75.0	83.1	70.3	75.7	67.3	71.3
SY Valda	85.1	102.1	80.4	93.1	79.8	90.2	59.2	72.3	58.7	72.1	57.2	66.0	72.1	87.2	69.6	82.6	68.5	78.1
TCG-Heartland	76.2	92.8	75.7	84.1	76.4	83.6	51.2	61.2	52.2	65.1	51.4	58.9	63.7	77.0	63.9	74.6	63.9	71.2
TCG-Spitfire	88.3	103.5	80.1	94.7	80.8	92.9	64.3	69.6	64.1	72.3	66.5	70.6	76.3	86.5	72.1	83.5	73.7	81.8
TCG-Wildcat	95.9	107.6	83.5	94.6	83.5	91.5	66.4	75.4	64.8	69.2	62.3	65.3	81.1	91.5	74.1	81.9	72.9	78.4
WB9479	84.9	97.1	77.5	85.2	77.8	82.6	56.3	64.4	52.8	63.6	51.8	58.5	70.6	80.8	65.2	74.4	64.8	70.6
WB9590	89.1	105.4	81.8	94.2	83.2	91.9	54.5	66.4	54.6	63.4	54.9	60.8	71.8	85.9	68.2	78.8	69.0	76.4
Mean (Bu/Acre)	88.4	100.5	81.4	90.6	80.3	86.7	58.7	65.7	58.0	66.5	56.8	62.1	73.6	83.1	69.7	78.5	68.5	74.4
LSD (0.10)	6.2	5.3	4.8	4.1	3.5	3.4	4.3	4.3	4.0	3.9	2.8	2.9	3.9	3.4	3.1	2.8	2.3	2.2
No. Environments	2	2	4	4	6	6	2	2	4	4	6	6	4	4	8	8	12	12

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Table 8. Agronomic characteristics of malting barley varieties, 2020-2022.

Variety	Origin[1]	Year of Release	PVP status	Heading (DAP)	Height (inches)	Stem Breakage (%)
2-row						
AAC Connect	AAFC	2017	Yes	58	25	8
AAC Synergy	AAFC	2012	Yes	59	26	6
ABI Cardinal	ABI	2021	Yes	59	25	16
Brewski	ND	2019	NA	58	26	14
Conlon	ND	1996	Yes	54	26	43
ND Genesis	ND	2015	Yes	57	28	18
Pinnacle	ND	2007	Yes	56	26	24
6-row						
Lacey	MN	2000	Yes	55	27	0
Quest	MN	2010	Yes	55	29	47
Rasmusson	MN	2008	Yes	54	26	2
Robust	MN	1984	Expired	55	29	5
Tradition	ABI	2003	Yes	54	27	0
No. of Environments				8	8	7

[1] Agriculture and Agri-Food Canada (AAFC), Anheuser-Busch InBev (ABI), North Dakota State University (ND), University of Minnesota (MN)

Table 9. Disease reactions of barley varieties in multiple year comparisons.

Variety	DON[1, 2]	Spot Blotch[1,3]	Net Blotch[1,4]	Stem Rust[1,5]	Bacterial Leaf Streak[1]
2-row					
AAC Connect	5	1	1	4	3
AAC Synergy	8	2	1	5	3
ABI Cardinal	7	5	2	5	5
Brewski	6	3	6	4	4
Conlon	3	9	2	3	6
ND Genesis	5	3	2	6	5
Pinnacle	5	6	9	6	6
6-row					
Lacey	7	1	2	4	5
Quest	5	6	2	4	6
Rasmusson	9	1	2	5	5
Robust	7	1	2	4	5
Tradition	4	2	1	5	6
No. of environments	4	1	2	3	3

[1]Trait measured on a scale from 0-9 where 0=resistant and 9=susceptible.

[2]Deoxynivalenol (DON) is the mycotoxin produced by the Fusarium head blight pathogen

[3]Data is for 2020 only

[4]Data for 2020 and 2022 only.

[5]Data is for stem rust pathogen QCCJ. All lines were resistant to stem rust pathogen MCCF in years tested.

Table 10. Relative grain yield (percent of the mean of the trial) of barley varieties in northern Minnesota locations in single-year (2022) and multiple year comparisons (2020-2022).

	Crookston		Hallock		Oklee		Perley		Roseau		Stephen		Strathcona
Variety	**2022**	**2 yr[1]**	**2022**	**3 yr**	**2022**	**3 yr**	**2022**	**3 yr**	**2022**	**2 yr[1]**	**2022**	**3 yr**	**2 yr[2]**
2-row													
AAC Connect	102	103	107	109	92	95	101	105	99	98	113	103	131
AAC Synergy	107	103	107	106	102	103	113	105	97	99	120	113	125
ABI Cardinal	79	94	104	109	105	101	105	100	96	100	108	98	126
Brewski	109	106	106	106	112	111	98	96	108	107	110	99	76
Conlon	87	85	94	95	91	91	86	89	97	100	82	100	67
ND Genesis	116	112	109	99	98	104	104	110	107	106	116	106	89
Pinnacle	91	99	91	96	108	105	99	105	112	112	97	104	110
6-row													
Lacey	98	99	88	86	92	97	89	93	98	99	80	95	97
Quest	106	101	95	89	105	99	100	96	90	86	89	93	101
Rasmusson	111	108	97	103	102	99	102	98	104	106	96	90	111
Robust	96	95	98	95	93	91	97	95	96	90	96	100	79
Tradition	96	94	104	107	100	104	104	108	97	95	94	99	88
Mean (bu/acre)	102	95	120	106	108	97	122	110	132	103	103	99	74
LSD(0.05)	20.7	19.1	11.1	14	17.1	11.5	11.2	14.6	14.4	10.5	10.9	19.7	51.5

[1]Trial data is from 2022 and 2021 only

[2]Trial data is from 2021 and 2020 only

Table 11. Relative grain yield (percent of the mean of the trial) of barley varieties in southern Minnesota locations in single-year (2022) and multiple year comparisons (2020-2022).

	Becker		Fergus Falls		Lamberton		Le Center		New Ulm		Rochester		St. Paul	
Variety	**2022**	**2 yr[1]**	**2022**	**3 yr**	**2022**	**3 yr**	**2022**	**3 yr**	**2022**	**3 yr**	**2022**	**3 yr**	**2022**	**3 yr**
2-row														
AAC Connect	103	99	103	104	95	98	109	104	101	104	97	91	96	105
AAC Synergy	102	110	100	100	99	104	89	95	108	95	109	103	103	110
ABI Cardinal	107	111	88	99	99	96	99	95	97	97	76	78	100	104
Brewski	106	118	95	104	99	108	100	99	93	96	104	95	111	121
Conlon	87	81	85	88	76	79	91	94	103	94	76	81	63	69
ND Genesis	88	94	116	105	108	101	93	102	82	98	106	103	102	103
Pinnacle	99	105	107	103	101	97	103	105	100	102	103	106	95	106
6-row														
Lacey	84	86	97	96	103	106	98	99	102	106	109	110	111	102
Quest	112	113	102	97	113	101	104	104	105	101	107	105	92	89
Rasmusson	121	111	113	107	104	111	104	103	105	108	113	118	118	107
Robust	81	76	87	91	96	95	95	92	100	95	99	102	99	88
Tradition	109	96	107	104	108	106	115	109	104	103	100	107	109	98
Mean (bu/acre)	96	65	125	107	70	66	103	93	82	84	82	91	62	69
LSD (0.050	14.3	20.8	12.9	14.7	9.7	13.1	16.5	10.6	16.1	16.8	13.1	16.8	12	13.7

[1] Trial data is from 2022 and 2021 only

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Table 12. Relative grain yield (percent of the mean of the trial) of barley varieties in a single-year (2022) and multiple year comparisons (2020-2022).

	State				North				South		
Variety	**2022**	**2 yr**	**3 yr**		**2022**	**2 yr**	**3 yr**		**2022**	**2 yr**	**3 yr**
2-row											
AAC Connect	102	103	103		102	104	105		101	103	101
AAC Synergy	104	102	104		107	105	107		101	98	101
ABI Cardinal	97	99	100		100	101	103		95	95	96
Brewski	104	102	103		107	102	102		100	102	104
Conlon	87	90	88		90	93	91		85	87	85
ND Genesis	104	105	103		108	107	104		100	102	102
Pinnacle	101	103	104		100	103	104		102	104	103
6-row											
Lacey	95	98	98		91	95	94		99	101	101
Quest	101	99	98		97	95	94		105	105	101
Rasmusson	106	106	105		102	102	101		111	109	109
Robust	95	93	93		96	94	93		93	91	92
Tradition	103	101	102		99	98	101		107	103	104
Mean (bu/acre)	101	90	90		113	101	99		90	79	83
LSD(0.05)	6.3	4.5	4.7		8.8	6.1	7.5		8	6.2	5.5
No. of environments	13	27	38		6	13	18		7	14	20

Table 13. Origin and agronomic characteristics of oat varieties in Minnesota in multiple-year comparisons (2020-2022).

Variety	**Origin**	**Year of Release**	**Legal Status**	**Seed Color**	**Days to Heading (days)**	**Plant Height (inches)**	**Straw Strength[4] (1-9)**	**Test Weight (lbs/bu)**	**Grain Protein[5,6] (%)**	**Grain Oil[5,6] (%)**	**Grain Beta-glucan[5,6] (%)**
Antigo	WI	2017	PVP(94)	Yellow	53.7	29.2	2	36.6	14.5	7.3	4.3
CS Camden[1]	Meridian Seeds	2013	PVP(94)	White	59.8	30	2.1	31.6	12.4	6.6	4.4
Deon	MN	2014	PVP(94)	Yellow	59.9	32.8	2.9	35	12.2	7.1	3.8
Esker 2020	WI	2020	PVP(94)	Yellow	55.4	29.9	2.2	32.4	12.6	6.2	4.2
George[2]	WI	2021	Pending	Yellow	62.6	33.8	4	32	-	-	-
Hayden	SD	2015	PVP(94)	White	58.6	32.2	2.9	34.8	11.9	7.3	4.5
MN Pearl	MN	2018	PVP(94)	White	57.8	31.5	4.2	35	11.2	7.4	4.1
ND Heart	ND	2020	PVP(94)	White	57.9	32	3.5	34.2	13.9	6.7	5
Reins	IL	2016	PVP(94)	White	54.1	24.2	0.9	35.7	13.8	6.3	4.2
Rushmore	SD	2020	PVP(94)	White	56	31	2	36.4	13.2	6.2	4.1
Saddle	SD	2018	PVP(94)	White	53.5	27.9	1	33.5	13.5	5.9	4
SD Buffalo	SD	2021	NA	White	56.5	31.7	2.3	34.8	12.6	7.2	4.5
Shelby 427	SD	2011	PVP(94)	White	55.1	31.8	2.2	35.7	12.5	7.2	4.1
Streaker[3]	SD	2016	PVP(94)	Hulless	56.1	31.1	4.2	44	13.3	7.4	4.2
Sumo	SD	2017	PVP(94)	White	51.6	29.7	2	35	14.5	6	3.8
Warrior	SD	2019	PVP(94)	White	56.6	29.5	1.4	35	12.8	6.5	4.1
WIX10305-4	WI	2022	NA	Yellow	59.8	29.3	1.4	32	14.6	6.8	4.4

[17]Line developed by Lantmannen Seed in Sweden.

[2]Line tested in 2021 and 2022

[3]Hulless oat

[4]1-9 scale where 1=most resistant, 9=most susceptible

[5]12% Grain moisture

[6]Trait measured for 3 locations in 2020

Table 14. Disease characteristics of oat varieties.

	Crown Rust2	Loose Smut3	BYDV[4]
Variety	(1-9)	(1-9)	(1-9)
Antigo	4	3	4
CS Camden	5	2	4
Deon	5	1	4
Esker 2020	4	1	3
George[1]	4	3	-
Hayden	5	12	3
MN Pearl	3	1	4
ND Heart[1]	4	6	4
Reins	5	1	4
Rushmore	4	2	4
Saddle	4	1	4
SD Buffalo	3	2	-
Shelby 427	5	1	4
Streaker	4	3	4
Sumo	4	2	4
Warrior	3	2	4
WIX10305-4	4	2	-

[1]Line tested in 2021 and 2022

[2]Tested in 2020, 2021, and 2022 with a mixed race population of crown rust; 1 = most resistant, 9 = most susceptible. Data is from 2020 and 2022 only; 2021 trial failed due to drought

[3]Tested in 2020 and 2021; 1 = most resistant, 9 = most susceptible. Data based on 2020 trial; 2021 trial had very low disease pressure due to drought

[4]Tested in 2021; 1 = most resistant, 9 = most susceptible

Table 15. Relative grain yield of oat varieties in northern Minnesota locations in single-year (2022) and multiple-year comparisons (2020-2022).

	Crookston			Fergus Falls[4]			Roseau			Stephen	
	2022	3 yr		2022	2 yr		2022	3 yr		2022	3 yr
Variety	------------------------------(% of mean)------------------------------										
Antigo	88	91		61	81		82	76		94	87
CS Camden	104	112		112	112		115	104		118	116
Deon	109	107		107	100		112	118		98	108
Esker 2020	107	108		90	91		112	103		96	97
George[1]	88	-		104	-		94	-		98	-
Hayden	110	113		116	113		111	113		106	107
MN Pearl	114	113		124	118		114	113		106	113
ND Heart	97	102		94	98		87	92		82	94
Reins	98	93		84	92		94	95		105	97
Rushmore	104	103		102	107		113	116		112	115
Saddle	100	93		93	92		101	102		111	101
SD Buffalo	113	109		113	111		111	113		113	112
Shelby 427	88	93		81	93		86	89		97	98
Streaker[2]	76	73		89	91		77	76		72	72
Sumo	80	78		97	80		84	88		97	87
Warrior	113	107		135	121		97	105		90	98
WIX10305-4	110	106		97	100		110	98		105	99
Mean (bu/acre)	187	157		135	124		189	136		177	149
LSD (0.05)[3]	29.8	20.2		27.4	24.8		28.5	21.7		30.6	24.1

[1]Line tested in 2021 and 2022 only

[2]Hulless oat

[3]A large LSD suggests large variability from year to year for the specific location

Continued on next page →

Table 16. Relative grain yield of oat varieties in southern Minnesota locations in single-year (2022) and multiple-year comparisons (2020-2022).

	Becker[3]			Lamberton			Le Center			Rochester			St. Paul[4]		Waseca	
Variety	2022	2 yr		2022	3 yr		2022	3 yr		2022	3 yr		2020		2022	3 yr
Antigo	110	97		89	91		101	101		86	98		85		78	85
CS Camden	124	118		106	100		105	104		84	85		101		121	120
Deon	86	90		118	114		104	105		115	111		111		93	107
Esker 2020	105	108		109	111		104	97		115	103		102		111	109
George[1]	90	100		103	-		86	-		112	-		-		103	-
Hayden	107	111		116	103		113	113		108	112		120		92	105
MN Pearl	90	95		97	108		97	101		103	102		130		104	119
ND Heart	87	90		101	99		99	98		83	91		92		106	88
Reins	102	97		87	93		95	97		69	86		103		88	97
Rushmore	87	92		95	103		103	109		107	111		100		114	110
Saddle	110	102		94	89		98	100		104	103		98		89	79
SD Buffalo	114	109		103	112		101	103		128	117		106		100	109
Shelby 427	93	100		91	86		96	103		104	106		105		81	91
Streaker[2]	65	67		75	73		81	81		69	73		78		82	82
Sumo	98	97		93	102		94	91		91	93		81		75	89
Warrior	118	112		100	108		104	97		99	100		114		104	98
WIX10305-4	114	114		121	109		121	100		124	107		75		157	114
Mean (bu/acre)	100	91		125	114		136	130		149	137		126		80	82
LSD (0.05)[5]	21.4	19.9		19.4	21.1		27.4	16.9		28.4	22.2		13		16.7	19.8

[1] Line tested in 2021 and 2022 only

[2] Hulless oat

[3] Location was tested in 2021 and 2022

[4] Location was tested in 2020 only

[5] A large LSD suggests large variability from year to year for the specific location

Table 17. Relative grain yield of oat varieties in Minnesota in single-year (2022) and multiple-year comparisons (2020-2022).

	North				South				State		
	2022	2 yr	3 yr		2022	2 yr	3 yr		2022	2 yr	3 yr
Variety	------------------------------(% of mean)------------------------------										
Antigo	82	83	84		93	94	94		87	88	89
CS Camden	112	111	111		105	104	102		109	108	107
Deon	107	110	108		105	107	107		106	108	108
Esker 2020	102	101	100		109	106	105		105	104	102
George[1]	95	98	-		99	96	-		97	97	-
Hayden	111	110	112		108	111	110		110	110	111
MN Pearl	114	114	114		98	102	107		107	108	111
ND Heart	90	94	97		94	93	94		92	94	95
Reins	96	91	94		87	91	94		92	91	94
Rushmore	108	107	110		101	102	106		105	105	108
Saddle	102	98	97		99	95	96		100	97	96
SD Buffalo	113	111	111		110	109	110		111	110	110
Shelby 427	89	92	93		94	99	98		91	95	96
Streaker[2]	78	77	77		74	76	76		76	76	77
Sumo	89	88	83		91	92	93		90	90	88
Warrior	107	108	107		104	103	103		106	105	105
WIX10305-4	106	108	101		125	117	105		115	112	103
Mean (bu/acre)	172	141	141		118	106	113		142	122	126
LSD (0.05)	20.3	13	11		16.1	10	9.2		13.4	8.5	7.3
# of environments	4	8	12		5	10	15		9	18	27

[1]Line tested in 2021 and 2022 only

[2]Hulless oat

North Dakota Hard Red Spring Wheat Variety Trial Results for 2022 and Selection Guide

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Hard red spring (HRS) wheat was planted on 5.4 million acres in 2022, down slightly from 5.5 million in 2021. The average yield of HRS wheat was 52 bushels/acre (bu/a), up substantially from 34 bu/a in 2021. Low 2021 yields were caused by wide-spread and severe drought. The 2022 growing season started with late planting after spring blizzards and heavy rains delayed field work for many across the state.

SY Valda was the most popular HRS wheat variety in 2022, occupying 11.0% of the planted acreage, followed by SY Ingmar (9.4%), AP Murdock (8.8%), WB9590 (8.8%), WB9719 (4.1%), Shelly (3.9%), ND Vitpro (3.0%), Elgin ND (3.0%), and Faller (2.9%). SY Valda, SY Ingmar, and AP Murdock were released by Syngenta/AgriPro. WB9590 and WB9719 were released by Westbred/Monsanto. Shelly is a University of Minnesota release and ND Vitpro, Elgin, and Faller are NDSU varieties.

Successful wheat production depends on numerous factors, including selecting the right variety for a particular area. The information included in this publication is meant to aid in selecting that variety or group of varieties. Characteristics to consider in selecting a variety may include yield potential, protein content when grown with proper fertility, straw strength, plant height, response to problematic pests (diseases, insects, etc.) and maturity. Every growing season differs; therefore, when selecting a variety, we recommend using data that summarize several years and locations. Choose the variety that, on average, performs the best at multiple locations near your farm during several years.

Selecting varieties with good milling and baking quality also is important to maintain market recognition and avoid discounts. Hard red spring wheat from the northern Great Plains is known around the world for its excellent end-use quality.

Millers and bakers consider many factors in determining the quality and value of wheat they purchase. Several key parameters are: high test weight (for optimum milling yield and flour color), high falling number (greater than 300 seconds indicates minimal sprout damage), high protein content (the majority of HRS wheat export markets want at least 14% protein) and excellent protein quality (for superior bread-making quality as indicated by traditional strong gluten proteins, high baking absorption and large bread loaf volume).

Gluten strength, and milling and baking quality ratings are provided for individual varieties based on the results from the NDSU field plot variety trials in multiple locations in 2021. The wheat protein data often are higher than obtained in actual production fields but can be used to compare relative differences among varieties.

The agronomic data presented in this publication are from replicated research plots using experimental designs that enable the use of statistical analysis. These analyses enable the reader to determine, at a predetermined level of confidence, if the differences observed among varieties are reliable or if they might be due to error inherent in the experimental process.

The LSD (least significant difference) values beneath the columns in the tables are derived from these statistical analyses and apply only to the numbers in the column in which they appear. If the difference between two varieties exceeds the LSD value, it means that with 95% or 90% confidence (LSD probability 0.05 or 0.10), the higher-yielding variety has a significant yield advantage. When the difference between two varieties is less than the LSD value, no significant difference was found between those two varieties under those growing conditions.

NS is used to indicate no significant difference for that trait among any of the varieties at the 95% or 90% level of confidence. The CV stands for coefficient of variation and is expressed as a percentage. The CV is a measure of variability in the trial. Large CVs mean a large amount of variation could not be attributed to differences in the varieties. Yield is reported at 13.5% moisture, while protein content is reported at 12% moisture content.

Presentation of data for the entries tested does not imply approval or endorsement by the authors or agencies conducting the test. North Dakota State University approves the reproduction of any table in the publication only if no portion is deleted, appropriate footnotes are given and the order of the data is not rearranged. Additional data from county sites are available from each Research Extension Center at https://vt.ag.ndsu.edu/.

Table 1. North Dakota hard red spring wheat variety descriptions, agronomic traits, 2022.

Variety	Agent or Origin[1]	Year Released	Height (inches)[2]	Straw Strength[3]	Days to Head[4]	Reaction to Disease[5,6] Leaf Rust	Tan Spot	Bact. Leaf Streak
AAC Brandon	**Canada**	**2012**	**31**	**4**	**49**	**6**	**NA**	**6**
AAC Starbuck	**Canada**	**2018**	**32**	**4**	**49**	**6**	**NA**	**6**
AAC Wheatland	**Canada**	**2018**	**31**	**4**	**49**	**4**	**NA**	**7**
AP Gunsmoke CL2	Syngenta/AgriPro	2021	30	6	48	3	4	8
AP Murdock	Syngenta/AgriPro	2019	28	4	49	5	4	6
AP Smith	Syngenta/AgriPro	2021	28	2	50	3	3	5
Ascend-SD	**SD**	**2022**	**34**	**4**	**50**	**4**	**NA**	**5**
Bolles	MN	2015	30	4	51	2	4	6
CAG-Justify	Champions Alliance Grp	2021	31	6	51	2	5	6
CAG-Reckless	Champions Alliance Grp	2021	32	5	49	2	6	6
CAG-Recoil	**Champions Alliance Grp**	**2022**	**29**	**3**	**55**	**1**	**NA**	**3**
CP3099A	Croplan	2020	32	5	52	3	4	6
CP3188	Croplan	2020	30	7	49	2	6	7
CP3530	Croplan	2015	33	7	50	5	6	6
Dagmar[7]	MT	2019	30	6	47	7	4	7
Driver	SD	2019	31	4	50	1	7	7
Faller	ND	2007	32	6	50	7	7	5
Glenn	ND	2005	33	4	47	6	6	5
Lanning	MT	2017	30	3	50	7	4	8
LCS Ascent	**Limagrain**	**2022**	**30**	**4**	**46**	**6**	**NA**	**6**
LCS Buster	Limagrain	2020	32	5	53	4	4	4
LCS Cannon	Limagrain	2018	29	4	45	7	5	7
LCS Dual	Limagrain		30	4	48	6	NA	7
LCS Hammer AX	**Limagrain**	**2022**	**29**	**4**	**47**	**6**	**NA**	**7**
LCS Rebel	Limagrain	2017	33	6	46	7	3	5
LCS Trigger	Limagrain	2016	33	5	54	1	4	4
MN- Rothsay	**MN**	**2022**	**29**	**3**	**51**	**6**	**NA**	**6**
MN-Torgy	MN	2020	31	4	50	3	3	4
MN-Washburn	MN	2019	30	3	51	1	6	6
MS Barracuda	Meridian Seeds	2018	28	4	45	NA	7	7
MS Charger	**Meridian Seeds**	**2022**	**29**	**7**	**47**	**2**	**NA**	**7**
MS Cobra	Meridian Seeds	2022	29	4	48	2	4	8
MS Ranchero	Meridian Seeds	2020	32	5	53	4	5	6
ND Frohberg	ND	2020	33	5	49	5	8	5
ND Heron	**ND**	**2021**	**31**	**6**	**46**	**7**	**NA**	**7**
ND VitPro	ND	2016	31	4	48	4	6	6
Shelly	**MN**	**2016**	**29**	**4**	**51**	**6**	**3**	**8**
SK Rush	**Canada**	**2016**	**33**	**4**	**50**	**2**	**NA**	**7**
SY 611CL2	Syngenta/AgriPro	2019	28	3	48	6	4	6
SY Ingmar	Syngenta/AgriPro	2014	29	3	50	3	6	6
SY Longmire[7]	Syngenta/AgriPro	2019	29	5	49	6	4	6
SY McCloud	Syngenta/AgriPro	2019	30	4	48	5	7	8
SY Valda	Syngenta/AgriPro	2015	29	5	49	2	7	6
TCG-Heartland	21st Century Genetics	2019	28	3	47	3	4	7
TCG-Spitfire	21st Century Genetics	2015	30	3	51	5	6	5
TCG-Wildcat	21st Century Genetics	2020	30	3	49	5	6	7
WB9590	WestBred	2017	27	3	48	3	8	8

[1] Refers to agent or developer: MN = University of Minnesota; MT = Montana State University; ND = North Dakota State University; SD = South Dakota State University; Canada = Agri-Food Canada. Bold varieties are those recently released, so data are limited and rating values may change.
[2] Height data averaged from multiple locations in 2022.
[3] Straw Strength = 1 to 9 scale, with 1 the strongest and 9 the weakest. These values are based on recent data and may change as more data become available.
[4] Days to Head = the number of days from planting to head emergence from the boot, averaged based on data from several locations in 2022.
[5] Disease reaction scores from 1 to 9, with 1 = resistant and 9 = very susceptible, NA = not available.
[6] All wheat varieties are resistant to moderately resistant to stem rust when screened using Puccinia graminis f. sp. tritici races TPMK, TMLK, RTQQ, QFCQ and QTHJ.
[7] Solid stemmed or semisolid stem, imparting resistance to sawfly.

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Table 2. Yield of hard red spring wheat varieties grown at five locations in eastern North Dakota, 2020-2022.

	Carrington		Casselton		Grand Forks		Langdon		Prosper		Average	
Variety	2022	3 Yr.	2022	3 Yr.	2022	3 Yr.	2022	3 Yr.[1]	2022	2 Yr.	2022	3 Yr.
	---(bu/a)---											
AAC Brandon	56.8	--	66.2	--	80.4	--	75.0	--	66.4	--	69.0	--
AAC Starbuck	60.7	--	69.5	--	77.5	--	80.1	--	55.9	--	68.7	--
AAC Wheatland	54.8	--	70.2	--	81.8	--	75.7	--	49.3	--	66.4	--
AP Gunsmoke CL2	57.7	54.0	72.9	--	86.1	--	80.6	--	50.8	73.5	69.6	--
AP Murdock	54.5	51.6	72.7	86.9	90.5	78.9	92.6	87.2	66.5	75.4	75.4	76.0
AP Smith	53.4	48.9	67.8	--	82.2	--	79.8	--	58.0	72.3	68.2	--
Ascend-SD	60.3	--	72.2	--	94.4	--	89.9	--	78.4	--	79.1	--
Bolles	46.1	45.7	74.4	77.0	83.1	69.7	71.0	70.5	42.0	61.7	63.3	64.9
CAG-Justify	60.7	--	74.7	--	78.8	--	92.6	--	50.3	70.9	71.4	--
CAG-Reckless	53.3	--	74.6	--	82.7	--	82.3	--	64.1	78.1	71.4	--
CAG-Recoil	53.2	--	62.3	--	95.1	--	85.5	--	75.3	--	74.3	--
CP3099A	59.7	--	83.7	--	87.8	--	81.8	--	57.9	78.2	74.2	--
CP3188	66.2	--	68.5	--	76.0	--	80.5	--	49.3	69.9	68.1	--
CP3530	58.7	54.4	71.9	85.3	86.5	77.6	86.7	82.7	63.9	70.3	73.5	74.1
Dagmar	62.8	56.0	68.4	80.8	89.3	75.6	68.7	--	54.7	68.3	68.8	--
Driver	58.3	56.6	77.5	86.7	87.5	78.9	81.9	--	51.6	73.6	71.4	--
Faller	59.4	56.7	71.0	82.8	81.5	77.2	85.7	83.3	69.9	80.5	73.5	76.1
Glenn	47.3	45.8	58.7	70.3	74.8	65.6	67.6	72.0	52.9	56.1	60.3	62.0
Lanning	49.2	47.5	67.9	81.7	78.5	69.7	60.5	--	60.2	71.1	63.3	--
LCS Ascent	51.4	--	79.9	--	90.5	--	85.0	--	57.1	--	72.8	--
LCS Buster	57.6	50.3	80.6	92.4	86.4	79.5	86.4	--	65.6	76.4	75.3	--
LCS Cannon	55.5	48.6	76.7	91.5	92.3	77.0	85.8	76.7	52.5	--	72.6	--
LCS Dual	65.9	--	76.4	--	88.7	--	73.1	--	46.2	--	70.1	--
LCS Hammer AX	63.2	--	76.7	--	87.8	--	79.5	--	63.6	--	74.2	--
LCS Rebel	64.4	55.4	76.9	82.0	78.9	76.3	76.7	77.8	64.3	76.7	72.2	73.6
LCS Trigger	58.6	55.4	80.7	90.6	91.2	85.3	93.5	87.1	81.3	87.4	81.1	81.2
MN-Rothsay	51.0	--	70.1	--	92.2	--	77.1	--	60.4	--	70.2	--
MN-Torgy	62.3	60.6	74.2	83.7	89.1	77.2	82.0	78.8	65.6	75.9	74.6	75.2
MN-Washburn	51.1	49.2	71.2	80.8	90.9	74.7	80.1	77.9	59.4	72.9	70.5	71.1
MS Barracuda	53.0	48.3	74.0	83.1	80.1	70.9	73.0	74.0	51.9	65.2	66.4	68.3
MS Charger	60.9	--	86.9	--	94.9	--	89.6	--	57.3	--	77.9	--
MS Cobra	60.6	--	76.4	--	78.3	--	67.5	--	47.9	66.8	66.2	--
MS Ranchero	55.6	55.4	66.2	82.4	80.2	75.3	76.1	--	50.4	62.3	65.7	--
ND Frohberg	54.9	48.2	72.2	82.3	79.4	69.8	77.4	77.2	62.0	73.7	69.2	70.3
ND Heron	48.5	42.8	66.7	--	79.1	--	68.0	71.1	56.5	--	63.8	--
ND VitPro	59.5	56.5	56.1	71.8	80.3	69.5	71.1	73.4	60.6	69.3	65.5	68.1
Shelly	65.0	59.0	78.3	--	86.1	73.5	76.0	71.9	46.5	--	70.4	--
SK Rush	46.9	--	60.5	--	74.8	--	75.5	--	59.4	--	63.4	--
SY 611CL2	57.3	48.8	67.1	81.4	82.2	72.9	81.6	80.9	58.5	76.2	69.3	72.0
SY Ingmar	50.4	46.6	66.5	77.9	81.9	72.6	75.3	77.8	50.1	67.5	64.8	68.5
SY Longmire	48.9	--	61.4	79.5	78.6	71.2	70.0	75.6	52.6	69.8	62.3	--
SY McCloud	52.2	50.5	75.9	84.2	84.8	71.7	75.4	76.5	54.4	71.2	68.5	70.8
SY Valda	55.2	53.9	71.8	85.8	93.9	77.6	86.1	81.7	62.6	77.2	73.9	75.2
TCG-Heartland	45.0	44.3	70.9	79.0	88.1	72.0	68.4	69.9	48.9	65.1	64.3	66.1
TCG-Spitfire	58.2	55.2	71.8	81.4	96.4	82.8	82.5	80.3	72.0	85.7	76.2	77.1
TCG-Wildcat	54.8	49.1	79.6	83.7	90.9	78.4	76.1	--	60.0	74.8	72.3	--
WB9590	56.7	--	78.9	--	97.4	--	74.4	--	50.3	68.5	71.5	--
Mean	56.3	51.6	71.9	82.5	85.3	74.9	78.6	77.5	59.2	72.2	70.1	71.7
CV%	9.9	--	4.4	--	6.5	--	7.7	--	12.1	--	8.2	--
LSD 0.05	7.8	--	5.8	--	6.2	--	8.4	--	8.1	--	7.1	--
LSD 0.10	6.6	--	4.5	--	5.2	--	7.1	--	6.8	--	6.0	--

[1] Langdon 3-year avg. includes 2019, 2020 and 2022.

Table 3. Yield of hard red spring wheat varieties grown at four locations in western North Dakota, 2020-2022.

	Hettinger		Mandan		Minot		Williston		Average	
Variety	**2022**	**3 Yr.**	**2022**	**3 Yr.**	**2022**	**3 Yr.**	**2022**	**3 Yr.**	**2022**	**3 Yr.**
	--------------------(bu/a)--------------------									
AAC Brandon	73.1	--	49.3	--	62.2	--	31.2	--	53.9	--
AAC Starbuck	76.1	--	51.6	--	52.4	--	33.3	--	53.4	--
AAC Wheatland	73.3	--	51.2	--	60.1	--	31.9	--	54.1	--
AP Gunsmoke CL2	78.8	50.5	66.4	43.8	57.7	--	34.8	--	59.4	--
AP Murdock	73.6	45.3	65.2	42.2	58.1	52.7	33.2	25.2	57.5	41.3
AP Smith	76.5	44.2	58.5	42.0	58.6	--	36.1	--	57.4	--
Ascend-SD	74.4	--	65.7	--	61.8	--	37.9	--	60.0	--
Bolles	70.3	43.1	56.5	38.5	61.5	55.4	31.6	24.3	55.0	40.3
CAG-Justify	82.4	--	67.2	--	66.7	--	33.8	--	62.5	--
CAG-Reckless	75.2	--	57.9	--	56.3	--	36.1	--	56.4	--
CAG-Recoil	76.4	--	66.6	--	66.9	--	37.7	--	61.9	--
CP3099A	76.8	--	62.8	--	68.7	--	34.6	--	60.7	--
CP3188	77.2	--	58.7	--	59.4	--	39.2	--	58.6	--
CP3530	76.0	48.0	58.4	41.1	55.5	56.8	33.4	--	55.8	--
Dagmar	82.6	51.7	57.7	39.0	60.9	53.7	30.7	26.9	58.0	42.8
Driver	76.9	50.4	57.0	43.7	63.0	--	32.1	26.6	57.3	--
Faller	79.2	50.8	61.2	44.3	72.0	64.6	31.1	28.0	60.9	46.9
Glenn	71.2	45.3	54.6	38.6	56.6	50.5	27.0	25.5	52.4	40.0
Lanning	77.3	48.9	56.0	41.9	63.4	55.9	34.6	28.9	57.8	43.9
LCS Ascent	80.9	--	54.9	--	65.1	--	33.9	--	58.7	--
LCS Buster	81.3	50.9	69.5	48.6	66.8	--	40.0	29.4	64.4	--
LCS Cannon	79.6	50.7	56.6	38.7	59.2	52.9	28.1	24.0	55.9	41.6
LCS Dual	80.2	--	55.1	--	72.7	--	32.8	--	60.2	--
LCS Hammer AX	77.6	--	62.8	--	60.4	--	36.8	--	59.4	--
LCS Rebel	78.2	51.0	58.5	40.8	61.0	56.5	34.9	28.4	58.2	44.2
LCS Trigger	77.1	50.3	70.4	47.6	66.7	64.9	36.5	29.2	62.7	48.0
MN-Rothsay	74.2	45.1	63.5	44.8	70.1	--	36.8	--	61.1	--
MN-Torgy	77.1	49.0	65.7	45.1	65.4	58.7	36.0	28.1	61.0	45.2
MN-Washburn	76.1	47.5	58.1	39.8	56.0	52.6	31.7	25.6	55.5	41.4
MS Barracuda	82.8	49.3	57.3	37.7	61.6	57.7	28.9	25.5	57.6	42.5
MS Charger	86.5	--	61.6	--	59.0	--	39.0	--	61.5	--
MS Cobra	77.7	--	62.1	--	55.2	--	32.9	--	57.0	--
MS Ranchero	78.2	51.0	64.3	46.8	52.1	--	33.3	27.0	57.0	--
ND Frohberg	73.7	47.3	57.9	40.6	58.0	53.0	34.4	26.5	56.0	41.9
ND Heron	74.3	48.0	54.2	37.7	55.9	--	30.5	--	53.7	--
ND VitPro	71.6	44.0	51.1	38.0	54.2	48.5	28.8	24.8	51.4	38.8
Shelly	78.9	--	60.9	--	63.8	56.8	32.1	--	58.9	--
SK Rush	76.1	--	57.0	--	50.4	--	36.3	--	54.9	--
SY 611CL2	81.4	50.3	60.7	41.7	56.5	57.4	36.4	29.6	58.7	44.8
SY Ingmar	65.1	42.0	54.3	38.6	53.5	48.8	36.8	28.6	52.4	39.5
SY Longmire	70.7	45.6	55.2	40.0	53.5	54.7	38.1	29.5	54.4	42.4
SY McCloud	76.9	47.9	59.8	39.6	66.7	53.7	34.6	26.3	59.5	41.9
SY Valda	74.8	48.1	60.8	44.6	57.4	51.4	35.4	26.9	57.1	42.7
TCG-Heartland	73.2	46.5	51.0	36.2	58.7	54.7	30.1	27.2	53.3	41.2
TCG-Spitfire	77.4	50.1	63.5	45.9	62.6	60.4	38.7	30.2	60.6	46.7
TCG-Wildcat	75.5	46.5	63.9	41.5	61.3	--	38.2	29.1	59.7	--
WB9590	77.6	--	57.2	--	59.0	--	30.6	--	56.1	--
Mean	76.6	47.8	59.4	41.6	60.9	55.3	34.5	27.3	57.7	42.8
CV%	3.1	--	6.5	--	8.7	--	7.1	--	6.4	--
LSD 0.05	2.8	--	4.5	--	8.6	--	4.0	--	5.1	--
LSD 0.10	2.2	--	3.5	--	7.2	--	3.3	--	4.3	--

Continued on next page

Table 4. Protein at 12% moisture of hard red spring wheat varieties grown at nine locations in North Dakota, 2022.

Variety	Carrington	Casselton	Grand Forks	Langdon	Prosper	Hettinger	Mandan	Minot	Williston	State Avg.
	(%)									
AAC Brandon	13.9	14.5	16.1	15.0	16.9	13.2	12.3	14.7	13.7	14.5
AAC Starbuck	13.7	15.3	16.5	15.3	17.3	14.1	13.2	14.1	14.7	14.9
AAC Wheatland	12.9	14.8	16.3	15.5	17.1	13.1	12.0	13.8	13.9	14.4
AP Gunsmoke CL2	12.0	14.3	15.5	14.8	17.0	12.6	11.4	13.3	15.0	14.0
AP Murdock	12.1	13.4	14.0	13.7	15.2	12.7	11.4	13.0	13.4	13.2
AP Smith	12.5	14.1	15.0	14.7	15.4	13.1	12.1	13.4	14.6	13.9
Ascend-SD	12.4	14.2	16.0	14.1	16.4	13.1	10.8	12.7	13.7	13.7
Bolles	14.1	15.9	16.5	15.8	17.4	13.6	13.4	13.9	16.0	15.2
CAG-Justify	11.1	13.5	14.8	13.1	15.7	12.2	10.6	12.0	13.5	12.9
CAG-Reckless	13.0	14.3	15.6	14.3	15.6	12.7	11.3	13.8	13.7	13.8
CAG-Recoil	12.6	13.5	14.4	14.4	15.4	13.2	11.2	12.6	13.6	13.4
CP3099A	11.6	12.6	13.8	12.5	14.6	11.7	10.8	12.1	12.2	12.4
CP3188	11.2	13.0	14.1	13.0	15.1	11.9	10.7	12.0	11.8	12.5
CP3530	12.7	14.5	15.1	14.7	16.2	13.3	11.4	14.3	14.3	14.1
Dagmar	13.1	14.5	15.8	15.6	16.4	12.4	11.5	14.8	15.9	14.4
Driver	12.0	13.9	15.0	13.9	15.7	12.5	11.7	13.4	14.2	13.6
Faller	11.7	13.3	14.9	13.6	15.2	12.2	11.1	12.1	13.3	13.0
Glenn	12.5	14.9	16.0	15.0	16.9	13.9	11.8	14.6	15.4	14.6
Lanning	12.6	14.6	16.3	15.3	16.7	13.4	12.0	13.1	13.2	14.1
LCS Ascent	11.5	13.4	13.8	13.6	15.4	12.0	11.0	13.5	13.6	13.1
LCS Buster	10.9	12.0	12.9	12.5	13.1	11.6	9.7	11.5	12.0	11.8
LCS Cannon	12.4	13.5	14.8	14.6	16.3	12.4	11.5	13.8	15.8	13.9
LCS Dual	12.3	13.2	15.0	13.9	16.2	12.0	11.1	13.1	13.2	13.3
LCS Hammer AX	12.0	13.9	14.3	14.4	15.5	12.2	11.4	13.7	13.6	13.4
LCS Rebel	12.4	14.5	15.4	14.6	16.5	12.5	12.7	14.0	14.0	14.1
LCS Trigger	11.0	12.1	13.0	12.1	13.1	11.3	9.4	11.4	12.6	11.8
MN-Rothsay	12.0	13.9	14.8	14.6	15.1	12.5	11.0	13.0	13.3	13.4
MN-Torgy	13.2	14.3	15.6	14.7	15.8	12.4	11.2	13.1	13.1	13.7
MN-Washburn	12.8	13.7	15.8	14.1	16.6	12.9	11.6	14.1	13.9	13.9
MS Barracuda	13.4	14.6	15.7	15.0	17.1	12.1	11.8	14.5	14.7	14.3
MS Charger	10.2	12.3	13.9	12.5	15.1	11.1	10.6	12.7	12.1	12.3
MS Cobra	11.9	14.3	15.6	15.0	17.0	13.1	12.2	14.2	14.2	14.2
MS Ranchero	11.9	13.7	14.9	14.2	15.7	12.6	10.4	13.5	13.3	13.4
ND Frohberg	12.7	13.5	15.4	14.2	16.0	13.5	11.9	13.9	14.9	14.0
ND Heron	11.8	14.8	15.9	15.1	16.8	13.4	11.8	14.6	15.5	14.4
ND VitPro	13.0	15.1	16.1	14.8	16.5	14.4	12.3	14.1	15.1	14.6
Shelly	12.3	13.3	14.9	14.1	15.2	12.6	10.7	12.9	13.1	13.2
SK Rush	12.8	15.0	16.0	14.9	16.6	13.2	11.6	13.9	14.2	14.2
SY 611CL2	11.9	14.1	15.3	14.6	16.3	13.0	11.7	13.7	13.6	13.8
SY Ingmar	13.3	14.5	15.6	15.0	15.9	14.2	12.6	14.4	15.1	14.5
SY Longmire	13.5	14.1	15.0	15.2	15.9	12.8	12.0	13.5	14.5	14.1
SY McCloud	14.6	14.4	15.7	15.0	16.1	13.9	12.4	14.5	14.6	14.6
SY Valda	11.3	13.2	15.0	14.1	15.4	12.9	11.0	13.4	12.9	13.2
TCG-Heartland	13.5	15.0	15.8	15.4	16.5	14.3	12.0	14.2	15.4	14.7
TCG-Spitfire	12.8	13.4	14.1	13.6	14.5	13.2	11.4	12.8	13.1	13.2
TCG-Wildcat	13.3	14.0	15.4	15.2	15.5	13.7	11.6	13.9	13.9	14.0
WB9590	12.0	14.5	15.3	15.0	16.8	13.5	11.8	13.8	14.9	14.2
Mean	12.4	14.0	15.2	14.3	15.9	12.8	11.5	13.4	13.9	13.7
CV%	7.7	1.3	2.0	2.8	2.1	3.5	4.0	4.8	4.4	3.3
LSD 0.05	1.3	0.4	0.3	0.6	0.4	0.5	0.6	1.0	1.0	0.4
LSD 0.10	1.1	0.3	0.3	0.5	0.3	0.4	0.5	0.9	0.8	0.4

Table 5. Yield of organic hard red spring wheat varieties grown at two locations in North Dakota, 2020-2022.

	Carrington		Dickinson	Average
Variety	**2022**	**3 Yr.**	**2022**	**2022**
	---(bu/a)---			
Barlow	16.3	17.3	58.4	37.3
Bolles	16.2	16.8	48.8	32.5
Ceres	11.5	15.3	52.9	32.2
Dagmar	16.7	20.1	66.8	41.7
Dapps	17.5	15.7	54.9	36.2
Driver	19.0	--	51.9	35.4
Elgin-ND	19.6	19.9	52.8	36.2
FBC Dylan	14.6	17.5	59.2	36.9
Faller	20.5	21.0	59.9	40.2
Glenn	15.5	17.5	56.3	35.9
Lang-MN	19.1	20.3	62.1	40.6
Lanning	16.0	20.5	61.7	38.9
Linkert	19.9	--	55.2	37.5
MN Rothsay	14.8	--	--	--
MN Washburn	17.1	16.3	54.2	35.6
MN-Torgy	17.8	--	69.0	43.4
Mida	12.6	16.4	45.8	29.2
ND Frohberg	15.8	19.6	51.6	33.7
ND Heron	17.0	--	63.3	40.1
ND VitPro	17.5	16.8	62.2	39.8
Prosper	20.3	--	68.0	44.2
Red Fife	16.4	22.2	51.6	34.0
Shelly	17.2	17.5	59.6	38.4
Mean	16.9	18.3	57.5	37.3
CV%	9.6	--	14.1	--
LSD 0.05	2.7	--	11.5	--
LSD 0.10	2.2	--	9.6	--

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Table 6. Quality data from 2018-2021. The Wheat Quality Index is a weighted average developed to summarize the relative milling and baking quality of lines in the trial. Data from across years are from 2018-2021 for all varieties which were tested in a minimum of two years (four locations per year) across North Dakota.

Variety	Test Weight[1]	Vitreous Kernels[2]	Wheat Protein[3]	Farinograph Absorption[4]	Flour Extraction[5]	Farinograph Stability[6]	Loaf Volume[7]	WQI RANK[8]
	lb/bu	%	12% m.b.	%	%	min	cm^3	
Bolles	61.3	80.1	16.8	65.4	64.6	22.8	980.9	1
WB9479	62.7	77.8	16.0	63.4	67.3	19.0	972.2	2
SY McCloud	63.1	75.7	15.4	67.0	67.0	11.2	978.2	3
Glenn	64.1	88.9	15.5	65.3	65.9	14.6	973.8	4
LCS Rebel	63.2	78.2	15.1	64.8	68.7	12.9	981.8	5
SY Longmire	62.4	77.2	15.1	65.1	67.5	12.4	1004.0	6
ND Frohberg	62.7	76.6	14.8	67.0	66.3	13.7	950.7	7
AAC Brandon	62.1	77.9	15.5	66.4	68.1	11.9	947.4	8
Dagmar	62.3	86.9	15.5	65.3	66.6	13.8	966.1	9
TCG-Heartland	63.1	75.6	15.5	64.3	67.9	15.0	946.5	10
ND VitPro	63.5	87.3	15.5	65.6	67.4	10.0	965.8	11
Lanning	61.4	83.3	15.4	64.3	66.4	11.3	1015.3	12
CP3530	61.7	68.8	14.7	64.8	68.3	11.3	995.4	13
SY Ingmar	62.7	78.7	15.2	63.7	67.7	13.3	974.5	14
MN-Rothsay	62.3	72.4	15.0	62.6	67.8	14.7	993.8	15
MN-Washburn	61.9	88.2	14.6	61.7	69.9	16.8	975.6	16
ND Hern	63.4	84.8	15.5	71.9	64.4	9.1	945.2	17
LCS Cannon	63.2	68.7	14.7	63.5	68.9	13.7	964.8	18
AP Murdock	61.7	62.3	14.8	65.1	67.6	13.6	949.5	19
Boost	61.4	80.6	15.2	65.7	66.8	10.2	953.3	20
WB9719	63.8	77.6	15.2	64.6	66.4	13.1	929.3	21
SY 611CL2	63.0	77.1	14.9	68.6	65.4	9.1	927.4	22
TCG-Spitfire	61.6	73.1	14.3	65.1	65.8	12.4	966.7	23
MS Ranchero	61.0	77.7	14.6	65.9	65.3	12.6	941.6	24
WB9590	62.4	76.4	15.5	63.9	67.3	13.8	915.4	25
MN-Torgy	62.5	70.3	15.1	62.9	66.2	15.3	938.4	26
TCG-Wildcat	62.9	78.4	14.9	64.5	67.3	8.9	946.9	27
Faller	61.7	69.9	14.4	64.6	68.4	10.3	931.7	28
Shelly	61.6	67.5	14.3	61.5	68.3	16.0	909.7	29
Driver	62.9	77.9	14.7	61.8	67.6	10.3	927.7	30
SY Valda	62.3	83.6	14.4	63.4	66.4	7.9	896.2	31
LCS Trigger	61.8	81.5	13.2	64.8	67.9	9.6	813.2	32
LCS Buster	60.1	68.0	13.2	58.6	68.9	15.1	864.3	33
Mean	62.4	77.2	15.0	64.6	67.2	12.9	949.8	17.0

[1] Test weight - Expressed in pounds (lbs) per bushel. A high test weight is desirable. A 58 lb test weight is required for a grade of US No. 1.
[2] Vitreous kernels - Expressed as a percentage of seeds having a vitreous-colored endosperm. A high percentage is desirable. US No. 1 DNS requires greater than 75% vitreous kernels.
[3] Wheat Protein - Measured by NIR at a 12% moisture basis. A high protein is desirable for baking quality.
[4] Farinograph Absorption - Measured by NIR at a 14% moisture basis. A measure of dough water absorption, expressed as percent. A high absorption is desirable.
[5] Flour Extraction - Percentage of milled flour recovered from cleaned and tempered wheat. A high flour extraction percentage is desirable.
[6] Farinograph Stability - A measure of dough strength expressed in minutes above the 500 Brabender unit line during mixing. A high stability is desirable.
[7] Loaf Volume - The volume of the pup loaf of bread, expressed in cubic centimeters. A high volume is desirable.
[8] Standardized means were used to calculate the Wheat Quality Index (WQI). The WQI is a weighted index calculated as: Test Weight (5%); Vitreous kernel (5%); Wheat Protein (10%); Flour Extraction (10%); Farinograph Absorption (23.3%); Farinograph Stability (23.3%) and Loaf Volume (23.3%). Adjusted means across locations were calculated for each trait using a mixed model. These means were standardized (mean=0 and standard deviation=1) to remove the effect of scale, which vary between traits.

Table 7. Quality data from 2021 from four locations across North Dakota. The Wheat Quality Index is a weighted average developed to summarize the relative milling and baking quality of lines in the trial. Data from 2021 are for all varieties which were tested in the 2022 trial. Data were collected from Carrington, Thompson, Hettinger, and Prosper, North Dakota.

Variety	Test Weight[1]	Vitreous Kernels[2]	Wheat Protein[3]	Farinograph Absorption[4]	Flour Extraction[5]	Farinograph Stability[6]	Loaf Volume[7]	WQI RANK[8]
	lb/bu	%	12% m.b.	%	%	min	cm^3	
CP3530	61.4	91.2	15.1	64.5	70.3	18.5	1046.1	1
MS Cobra	62.2	93.5	15.0	65.5	68.4	16.2	1064.5	2
SY Longmire	62.5	93.6	14.6	63.8	68.5	20.9	1043.9	3
SY McCloud	63.4	93.5	15.4	66.6	68.5	16.9	967.9	4
Lanning	61.6	93.6	15.1	63.5	69.3	18.3	1040.7	5
WB9479	62.9	92.7	15.9	63.2	68.1	23.1	971.2	6
Dagmar	62.4	93.7	15.3	64.8	66.8	20.5	970.1	7
MN-Washburn	62.3	94.3	14.6	61.0	70.0	25.1	999.4	8
TCG-Heartland	63.0	91.9	15.7	63.6	67.7	20.3	958.1	9
CAG-Reckless	62.5	91.0	15.0	64.5	65.8	19.5	997.2	10
LCS Rebel	63.2	94.0	15.1	63.5	68.8	18.8	961.4	11
AP smith	61.8	90.0	14.9	62.4	66.9	22.6	1003.7	12
LCS Cannon	63.6	88.7	14.6	62.3	68.9	21.4	967.9	13
TCG Spitfire	61.3	91.7	14.6	64.7	67.0	17.1	982.0	14
Glenn	64.1	94.0	15.2	64.5	66.0	19.5	927.7	15
ND VitPro	63.3	94.2	15.5	64.8	67.0	14.5	945.1	16
Bolles	61.4	90.8	16.6	64.6	64.7	22.9	903.8	17
AP Murdock	61.5	88.1	14.8	63.6	67.9	18.2	955.9	18
SY 611CL2	63.0	93.5	14.7	67.5	65.4	14.0	948.3	19
ND Frohberg	62.7	92.4	14.8	66.1	66.0	18.9	889.7	20
MN-Rothsay	62.8	90.0	14.8	61.9	67.9	17.7	991.8	21
SY Ingmar	62.7	94.2	15.0	62.8	67.4	19.3	940.7	22
WB9590	62.7	90.6	15.2	63.5	67.3	19.1	920.1	23
MN-Torgy	62.9	92.8	14.9	61.8	67.1	20.9	961.4	24
Ascend-SD	61.4	94.2	15.0	63.1	66.2	15.0	1003.6	25
MS Ranchero	61.9	92.6	14.3	65.2	66.0	16.6	925.5	26
AP Gunsmoke CL2	61.5	92.3	15.4	61.5	67.7	18.6	945.1	27
TCG-Wildcat	62.7	93.8	14.7	63.3	67.7	12.7	945.1	28
ND Heron	63.6	93.7	15.5	71.5	63.8	12.0	886.4	29
Driver	63.1	91.3	14.4	60.6	68.8	15.0	951.6	30
Faller	61.6	89.6	14.4	64.0	68.3	14.7	870.2	31
CP3188	61.0	86.0	13.7	59.5	68.4	24.0	906.0	32
CAG-Justify	59.4	93.5	14.1	62.1	68.6	12.9	908.2	33
SY Valda	62.5	93.9	14.6	62.8	66.1	12.0	869.1	34
CP3099A	59.2	89.5	13.2	60.6	67.2	17.7	936.4	35
LCS Trigger	61.3	92.8	13.6	62.9	67.1	15.2	835.4	36
LCS Buster	60.2	85.3	13.0	56.6	69.0	20.2	834.3	37
Mean	62.0	92.1	14.8	63.3	67.5	17.9	955.6	

See footnotes below Table 6.

North Dakota barley yields 2022

Clair Keene

Barley was seeded on 740,000 acres in North Dakota in 2022, up from 580,000 acres in 2021. The average state yield was estimated at 73 bushels per acre, up from 51 bushels per acre during the drought of 2021. In much of the state, barley along with other crops were seeded late after April blizzards and May rains delayed planting. Barley yields in eastern North Dakota were good with variety trials averaging 95.5, 85.1, and 102.5 busxhels per acre at Fargo, Carrington, and Langdon, respectively. In western North Dakota, trials at Glen Ullin, Hettinger, Minot, and Williston yielded 62.0, 99.4, 87.8, and 36.9 bushels per acre, respectively. AAC Synergy, ND Genesis, and Brewski were top yielders in eastern locations. In the west, ABI Cardinal was the highest yielding variety across all locations. CDC Austenson was only planted at Minot and Hettinger but was the highest yielding at both. No major issues with plump or protein were observed with trials averaging 92.4% plump and 11.0% protein in the east and 92% plump and 11.5% protein in the west.

Table 1. 2022 North Dakota barley variety descriptions.

					Rachilla					Reaction to Disease[6]			
Variety	**Use[1]**	**Origin[2]**	**Year Released**	**Awn[3] Type**	**Hair[4] Length**	**Aleurone Color**	**Height (inch)**	**Days to Head**	**Straw[5] Strength**	**Stem Rust**	**Spot-form Net Blotch**	**Spot Blotch**	**Net Blotch**
Six-rowed													
Tradition	M/F	BARI	2003	S	L	White	30	48	3	8	6	3	7
Two-rowed													
AAC Connect	M/F	Can.	2017	R	L	White	27	55	4	4	5	4	5
AAC Synergy	M/F	Syngenta	2015	R	L	White	29	55	4	4	3	4	4
ABI Cardinal	M/F	BARI	2019	R	S	White	28	56	4	NA	NA	4	6
Brewski	M	ND	2021	S	L	White	28	54	4	NA	NA	4	4
CDC Austenson	F	CDC	2009	R	S	White	29	57	2	NA	NA	2	2
CDC Churchill	M/F	CDC	2019	R	L	White	NA	NA	3	NA	3	3	NA
CDC Fraser	M/F	CDC	2016	R	L	White	27	56	2	NA	NA	4	4
Conlon[7]	M/F	ND	1996	S	L	White	28	49	5	8	4	6	3
Explorer	M	Secobra	NA	R	L	White	24	55	3	NA	NA	8	4
ND Genesis	M/F	ND	2015	S	L	White	30	52	4	8	4	4	6
Pinnacle	M/F	ND	2006	S	L	White	29	50	3	8	8	5	6

Bolded varieties were tested for the first time this year, so some ratings may change as new data become available.
[1] M = malting; F = feed.
[2] BARI = Busch Agricultural Resources Inc.; CDC = Crop Development Centre, University of Saskatchewan; ND = North Dakota State University
[3] R = rough; S = smooth.
[4] L = long S = short.
[5] Straw Strength scores from 1-9, with 1 = strongest and 9 = weakest.
[6] Disease reaction scores from 1-9, with 1 = resistant and 9 = very susceptible, NA – not available.
[7] Lower DON accumulations than other varieties tested.

Table 2. Yield and test weight of barley varieties at three locations in eastern North Dakota, 2020-2022.

	Fargo			Carrington			Langdon			Avg. eastern N.D.		
	Test	Yield		Test	Yield		Test	Yield		Test	Yield	
Variety	Wt.	2022	3 Yr.	Wt.	2022	3 Yr.	Wt.	2022	3 Yr.	Wt.	2022	3 Yr.
	(lb/bu)	-----(bu/a)-----		(lb/bu)	-----(bu/a)-----		(lb/bu)	-----(bu/a)-----		(lb/bu)	-----(bu/a)-----	
Six-rowed												
Tradition	48.5	105.8	117.1	48.5	81.9	73.6	50.0	98.5	98.8	49.0	95.4	96.5
Two-rowed												
AAC Connect	49.9	93.6	103.0	46.9	86.7	74.3	49.5	100.1	105.5	48.8	93.5	94.3
AAC Synergy	49.9	104.2	103.2	48.8	94.0	77.1	50.5	105.2	109.8	49.7	101.1	96.7
ABI Cardinal	51.2	94.2	102.7	48.1	85.3	--	50.6	103.3	98.3	50.0	94.3	--
Brewski	49.5	99.0	100.1	46.7	87.8	--	50.1	108.6	--	48.8	98.5	--
CDC Austenson	--	--	--	52.6	89.7	--	--	--	--	--	--	--
CDC Fraser	49.2	91.1	97.5	47.2	81.4	--	49.4	105.2	--	48.6	92.6	--
Conlon	50.5	82.6	92.8	48.4	78.6	67.1	51.1	100.0	88.7	50.0	87.1	82.9
Explorer	54.2	81.5	95.8	47.7	85.5	73.2	48.9	105.6	95.1	50.3	90.9	88.0
ND Genesis	50.9	111.0	111.7	46.4	87.0	71.6	48.8	100.4	107.5	48.7	99.5	96.9
Pinnacle	49.4	92.0	100.0	48.2	78.5	70.7	51.6	98.5	96.2	49.7	89.7	89.0
Mean	50.3	95.5	102.4	48.1	85.1	72.5	50.1	102.5	100.0	49.4	94.2	92.0
CV %	--	7.8	--	2.1	8.6	--	1.1	5.0	--	2.4	6.1	--
LSD 0.05	--	11.8	--	1.4	10.5	--	0.8	7.6	--	NS	NS	--
LSD 0.10	--	9.9	--	1.2	8.8	--	0.7	6.3	--	1.7	NS	--

Table 3. Plump and protein of barley varieties at three locations in eastern North Dakota, 2022.

		Fargo			Carrington			Langdon			Avg. eastern N.D.	
Variety		Plump	Protein		Plump	Protein		Plump	Protein		Plump	Protein
		(%)	(%)		(%)	(%)		(%)	(%)		(%)	(%)
Six-rowed												
Tradition		69.7	12.7		95	11.8		95	10.9		86.7	11.8
Two-rowed												
AAC Connect		81.1	12.0		90	11.1		95	10.3		88.6	11.1
AAC Synergy		87.1	12.3		96	10.9		97	10.4		93.3	11.2
ABI Cardinal		85.1	12.5		95	10.7		97	10.3		92.5	11.2
Brewski		91.6	11.2		96	11.0		96	10.1		94.7	10.8
CDC Austenson		--	--		92	10.8		--	--		--	--
CDC Fraser		88.7	13.1		95	11.1		97	10.3		93.5	11.5
Conlon		90.2	12.6		96	11.7		98	10.5		94.9	11.6
Explorer		91.4	11.5		93	10.8		95	9.7		93.2	10.7
ND Genesis		92.1	10.2		95	10.1		95	9.7		93.9	10.0
Pinnacle		85.0	10.9		96	10.2		97	10.0		92.6	10.4
Mean		86.2	11.9		95	10.9		96	10.2		92.4	11.0
CV %		--	--		2.1	4.6		1.8	4.6		--	--
LSD 0.05		--	--		2.8	0.7		2.4	0.7		--	--
LSD 0.10		--	--		2.4	0.6		2.0	0.6		--	--

Continued on next page →

Table 4. Yield and test weight of barley varieties at four locations in western North Dakota, 2020-2022.

	Glen Ullin			Hettinger			Minot			Williston			Avg. western N.D.		
	Test	Yield		Test	Yield		Test	Yield		Test	Yield		Test	Yield	
Variety	**Wt.**	**2022**	**3 Yr.**	**Wt.**	**2022**	**3 Yr.**	**Wt.**	**2022**	**3 Yr.**	**Wt.**	**2022**	**3 Yr.**	**Wt.**	**2022**	**3 Yr.**[1]
	(lb/bu)	---(bu/a)---		(lb/bu)	---(bu/a)---		(lb/bu)	---(bu/a)---		(lb/bu)	---(bu/a)---		(lb/bu)	---(bu/a)---	
Six-rowed															
Tradition	45.8	41.0	60.9	47.5	101.6	62.1	45.1	84.0	94.3	45.8	41.8	31.8	46.1	67.1	62.3
Two-rowed															
AAC Connect	44.4	62.1	--	47.0	94.6	61.3	45.8	90.0	104.6	45.4	41.2	31.0	45.6	72.0	--
AAC Synergy	46.0	56.9	79.4	47.8	103.4	64.1	44.5	85.1	101.7	45.2	42.1	31.4	45.9	71.9	69.1
ABI Cardinal	47.1	68.3	--	47.7	93.9	62.9	47.7	95.6	102.8	46.0	47.3	--	47.1	76.3	--
Brewski	45.4	74.0	--	47.1	105.1	70.0	45.6	82.5	--	43.9	37.1	--	45.5	74.7	--
CDC Austenson	--	--	--	50.1	111.9	--	47.1	94.4	--	--	--	--	--	--	--
CDC Fraser	45.8	63.8	--	46.9	101.2	--	46.0	86.4	--	45.5	37.7	--	46.0	72.3	--
Conlon	--	--	--	48.5	95.2	55.2	47.5	90.1	93.1	46.9	27.2	28.5	--	--	--
Explorer	--	--	--	46.6	105.3	67.6	47.5	93.0	103.4	46.7	41.6	35.0	--	--	--
ND Genesis	45.4	67.6	80.8	47.9	95.6	66.9	44.9	86.4	105.1	44.2	37.6	32.4	45.6	71.8	71.3
Pinnacle	--	--	--	46.2	85.7	59.9	45.2	78.8	99.0	46.6	34.0	31.4	--	--	--
Mean	45.7	62.0	73.7	47.6	99.4	63.3	46.1	87.8	100.5	45.6	36.9	31.6	46.0	72.3	67.6
CV %	1.3	8.3	--	1.6	5.2	--	1.6	4.9	--	1.4	8.5	--	1.7	8.5	--
LSD 0.05	0.9	7.4	--	0.9	6.1	--	1.2	7.4	--	1.1	5.2	--	1.2	NS	--
LSD 0.10	0.7	6.1	--	0.7	4.7	--	1.0	6.1	--	0.9	4.3	--	1.0	7.6	--

[1] Glen Ullin excluded from three-year average.

Table 5. Plump and protein of barley varieties at four locations in western North Dakota, 2022.

	Glen Ullin		Hettinger		Minot	Williston	Avg. western N.D.	
Variety	**Plump**	**Protein**	**Plump**	**Protein**	**Protein**	**Protein**	**Plump**	**Protein**
	---(%)---							
Six-rowed								
Tradition	95	11.7	91	13.9	12.3	11.4	93	12.3
Two-rowed								
AAC Connect	88	11.3	85	12.9	11.8	10.3	87	11.6
AAC Synergy	93	10.6	92	12.4	12.9	10.8	92	11.7
ABI Cardinal	95	11.2	90	12.4	11.9	9.9	93	11.4
Brewski	95	9.8	90	11.7	11.6	11.2	93	11.1
CDC Austenson	--	--	89	12.3	12.3	--	--	--
CDC Fraser	96	11.5	91	12.4	12.9	11.3	94	12.0
Conlon	--	--	95	13.1	12.7	11.0	--	--
Explorer	--	--	86	13.6	11.8	10.2	--	--
ND Genesis	94	9.6	92	11.2	10.8	9.7	93	10.3
Pinnacle	--	--	85	11.7	10.7	9.5	--	--
Mean	94	10.8	90	12.5	12.0	10.4	92	11.5
CV %	2.0	4.0	3.1	5.8	3.4	5.5	--	--
LSD 0.05	3	0.6	3.2	0.8	0.6	0.9	--	--
LSD 0.10	2	0.5	2.5	0.7	0.5	0.8	--	--

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